The Universe

What is it?

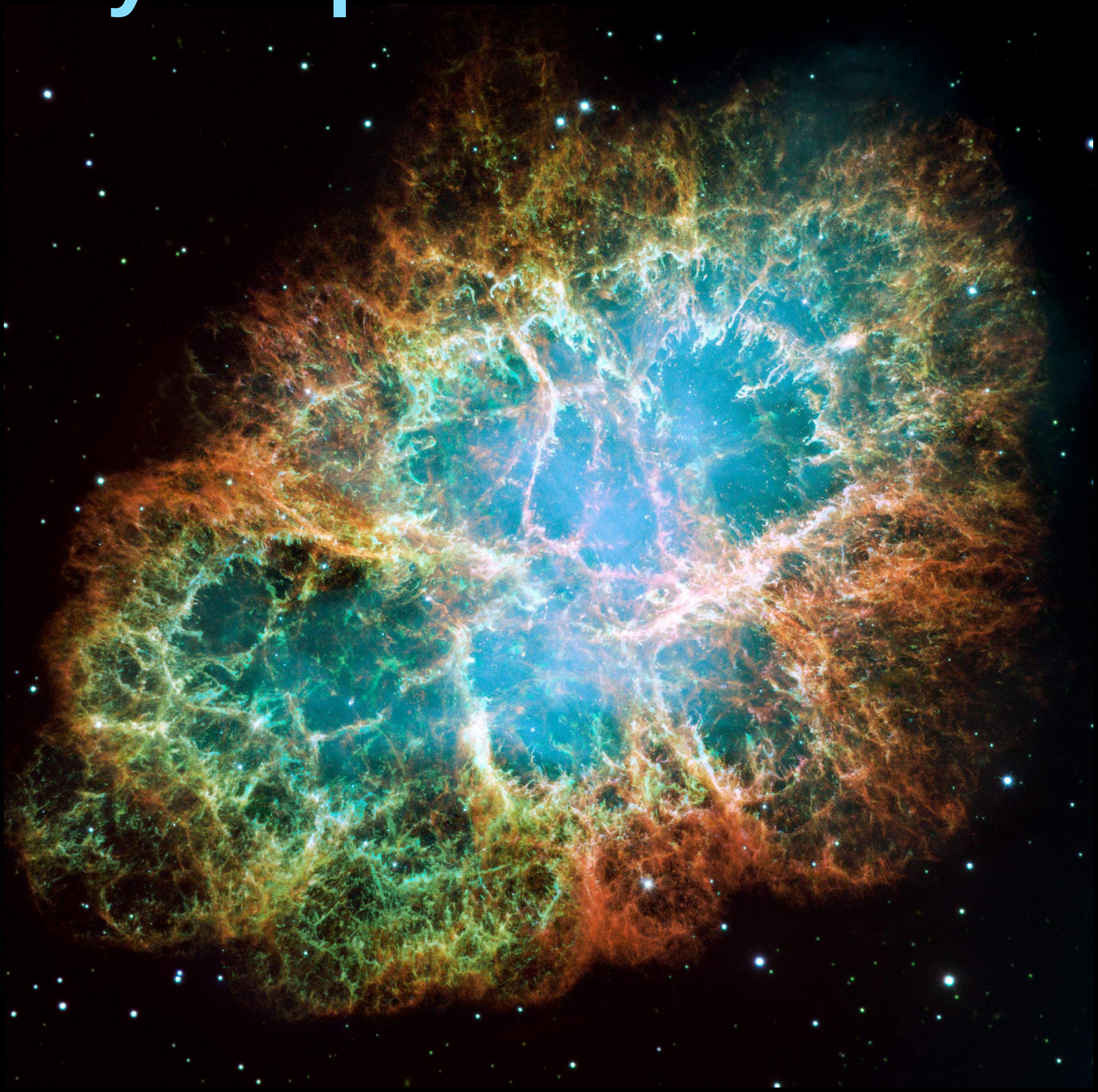
What is in it?

How did it form?

How will it end?

How do we know?

What is your place in the Universe?



What is the universe?

a. The study of the universe – its nature, origins, and evolution – is called **cosmology**.

b. The **Universe** is all space and time (*spacetime*) and everything in it.

   i) Includes **everything** – all galaxies, stars, planets, moons, you, etc.

   – all matter and energy.

ii) Age: **The universe is 13.8 billion years old.**

- **Time** – light from the sun takes about 8 minutes to reach the earth, so when you observe the sun, you see it as it was 8 minutes ago. **The farther back in space you look, the farther back in time you see.**

- When the Hubble Space Telescope looks as far as it can, it observes galaxies that are 13.8 billion light years away. Thus, the observable universe is 13.8 billion years old.

iii) Size: **The universe is currently expanding and accelerating.**

- The observable universe is 28 billion light years across.
- The entire universe is much larger…

92 billion light years?

7 trillion light years?

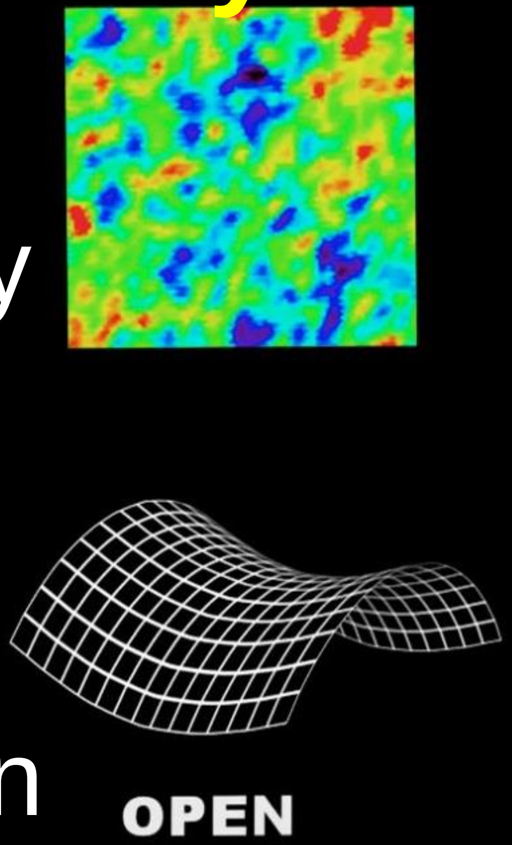
Infinite?

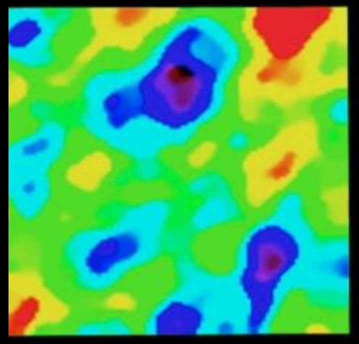
iv) **Structure: the size of the universe depends on its geometry:**

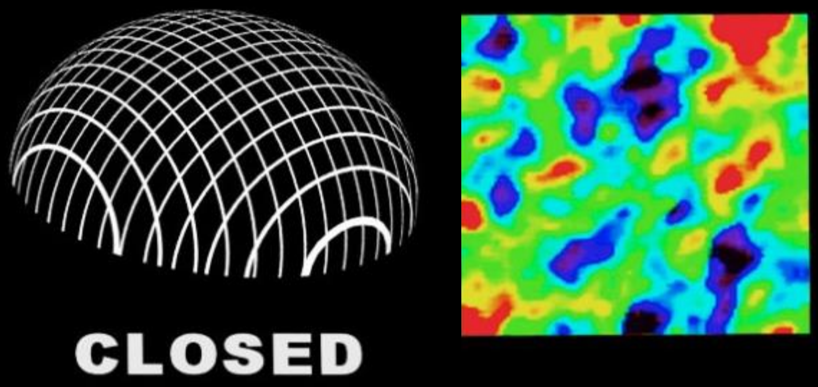
- **Open universe**
  Expansion > gravity
  Accelerated expansion forever

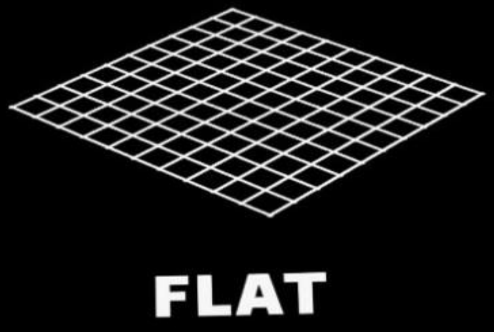
- **Closed universe**
  Gravity > expansion
  Expansion stops, universe collapse

- **Flat universe**
  Expansion = gravity
  Expansion slows, universe remains the same forever









C. What is the universe made of?

a. Cosmologists estimate that the universe is comprised of:

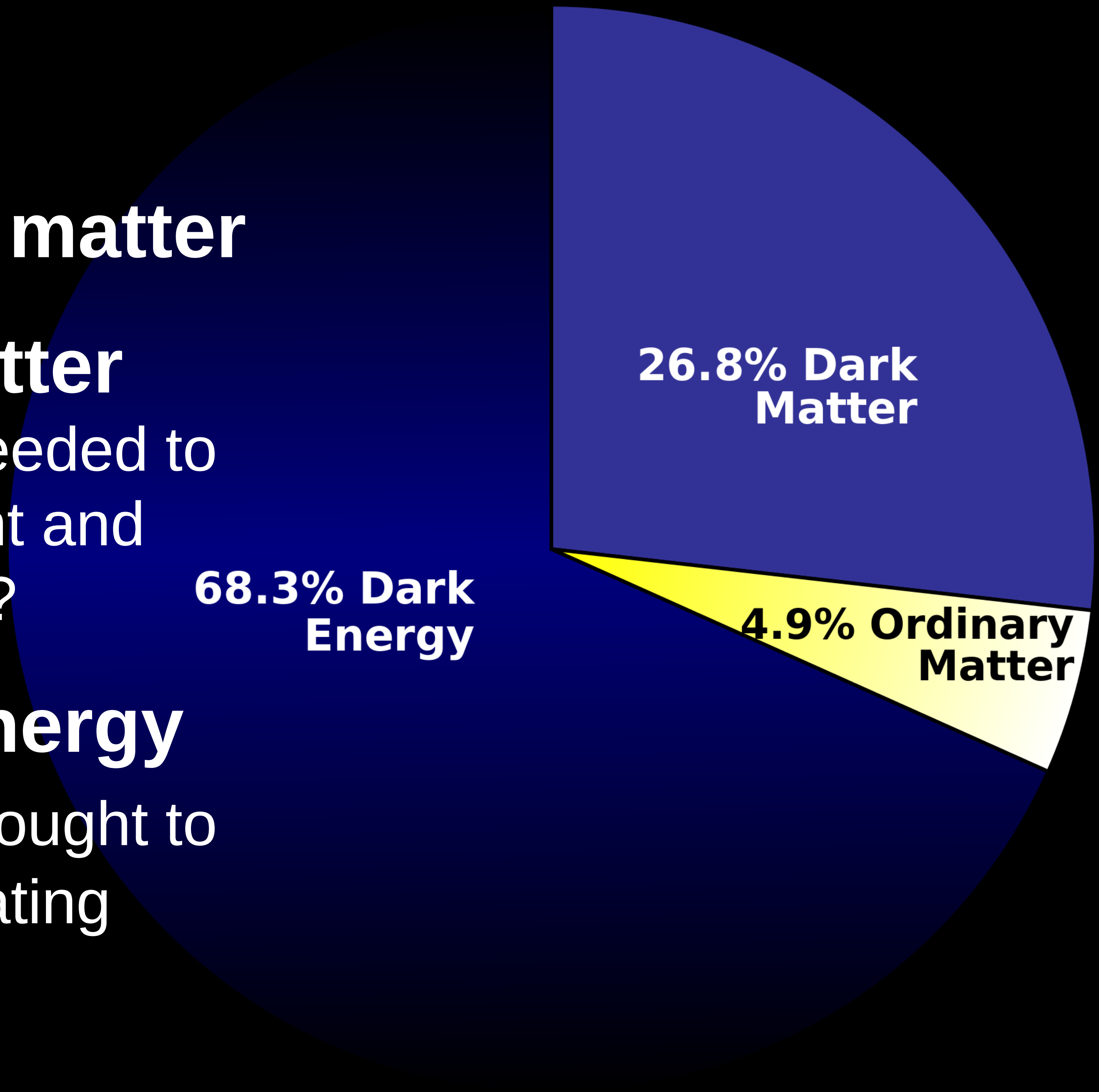
i. **4.9% ordinary matter**

ii. **26.8% dark matter**

-never observed, needed to explain bending light and curious star motion?

iii. **68.3% dark energy**

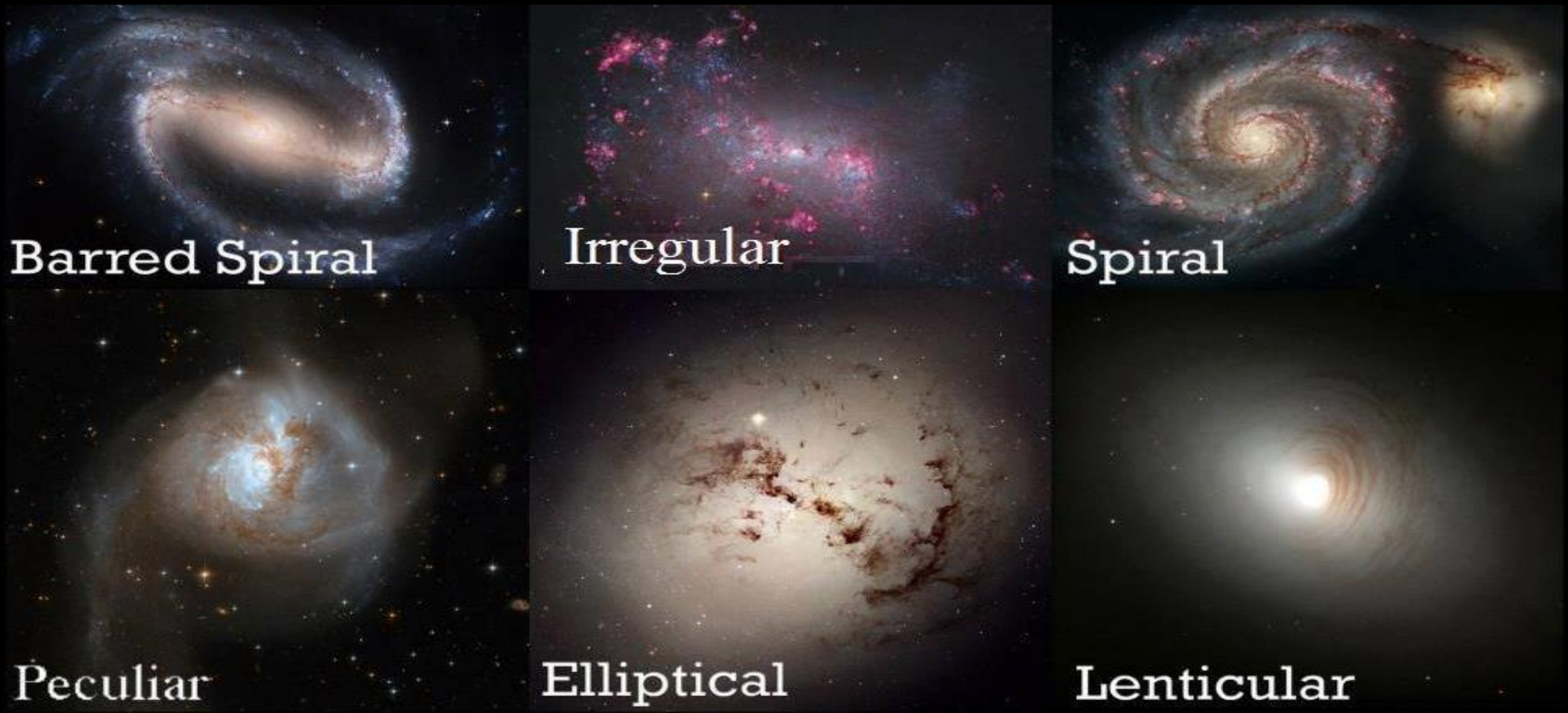
-never observed, thought to explain the accelerating expansion.



Contents of the Universe

i. **Galaxies** = a very large group of stars and material bound gravitationally.

- the universe contains gravitationally bound clusters and groups of galaxies.
- Types of galaxies – Spiral/barred spiral, elliptical, and irregular




You are here.

Our **Milky Way Galaxy**

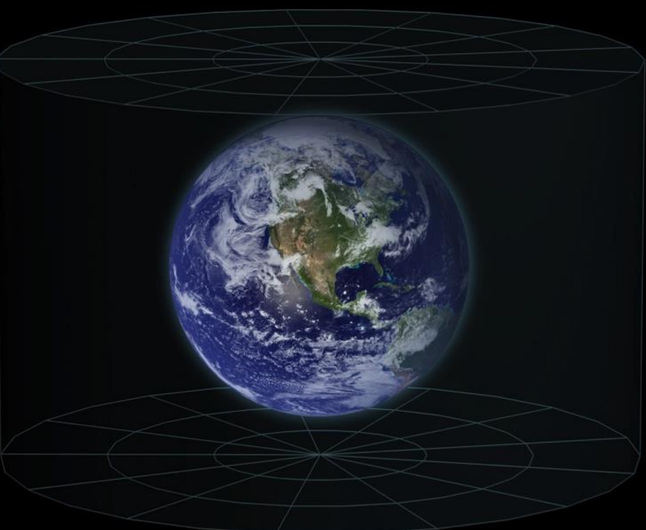
YOU ARE HERE

- Scientists now believe that there is a **supermassive black hole** at the galactic center of every galaxy, providing the source of gravity for the stars to revolve around.

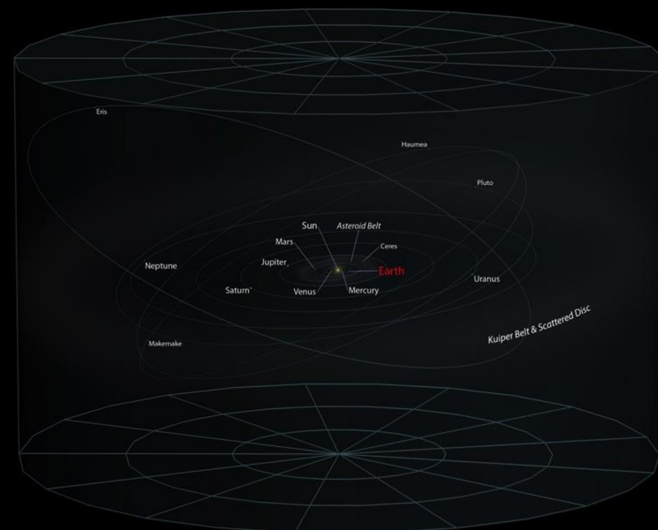
- The galaxy we exist in is the **Milky Way Galaxy**, located in the Local Group, which itself is located in the Virgo Supercluster.

Our Cosmic Address

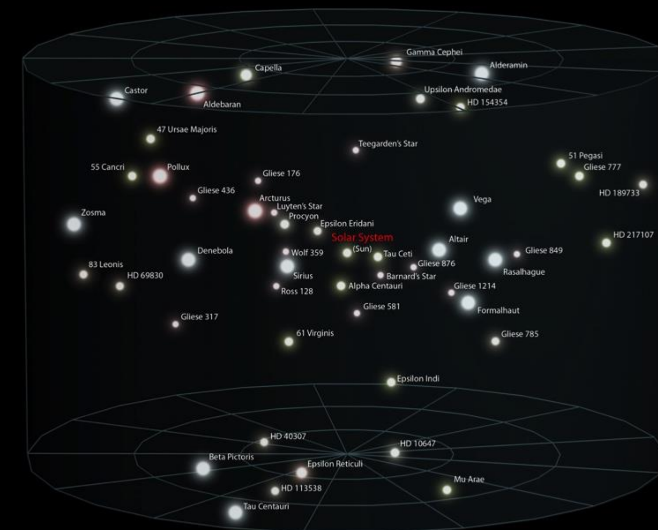
EARTH



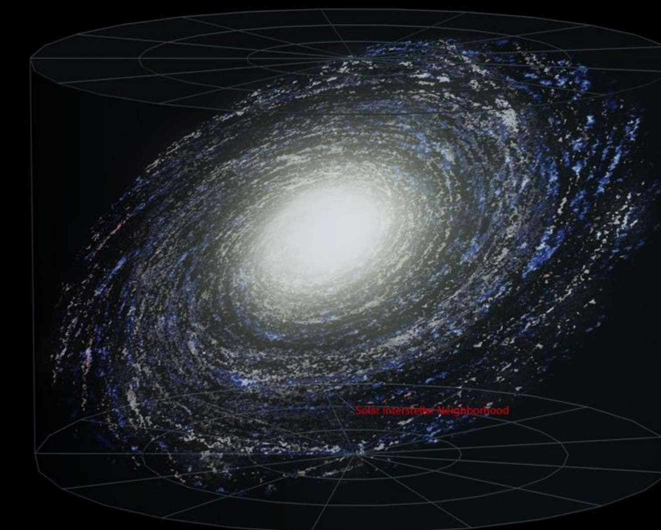
SOLAR SYSTEM



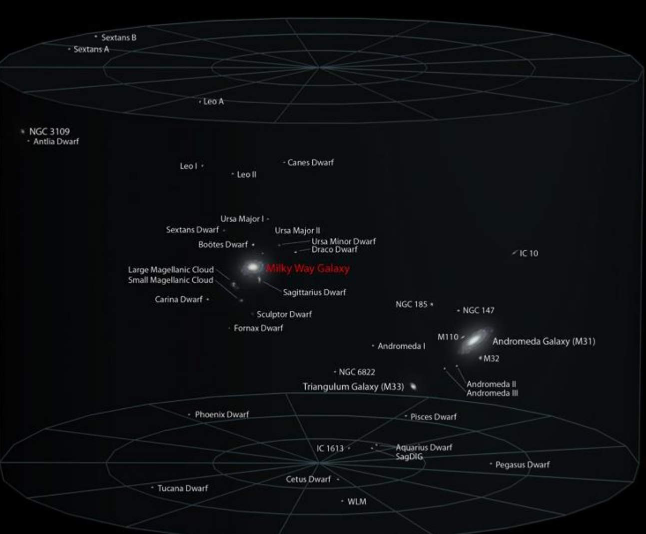
INTERSTELLAR NEIGHBORHOOD



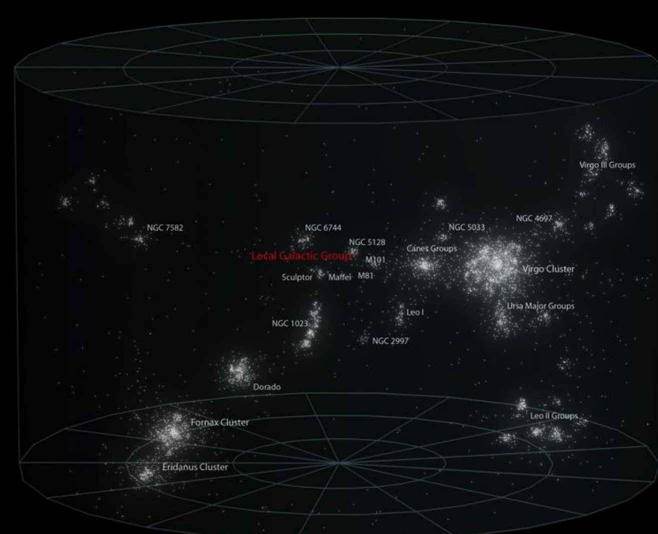
MILKY WAY GALAXY



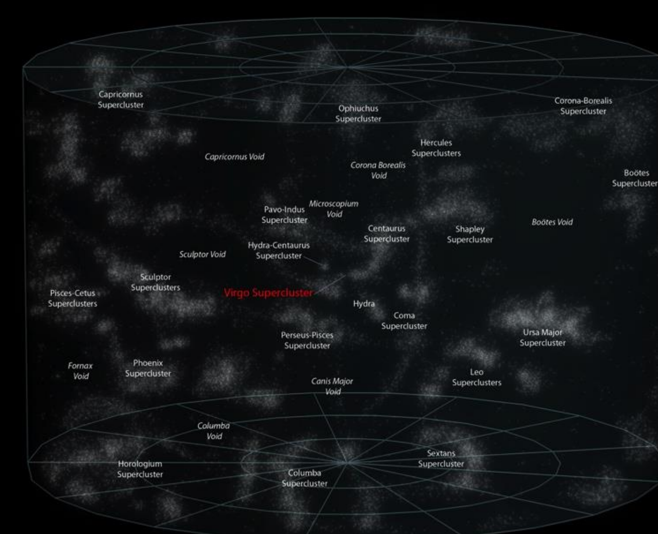
LOCAL GALACTIC GROUP



VIRGO SUPERCLUSTER



LOCAL SUPERCLUSTERS



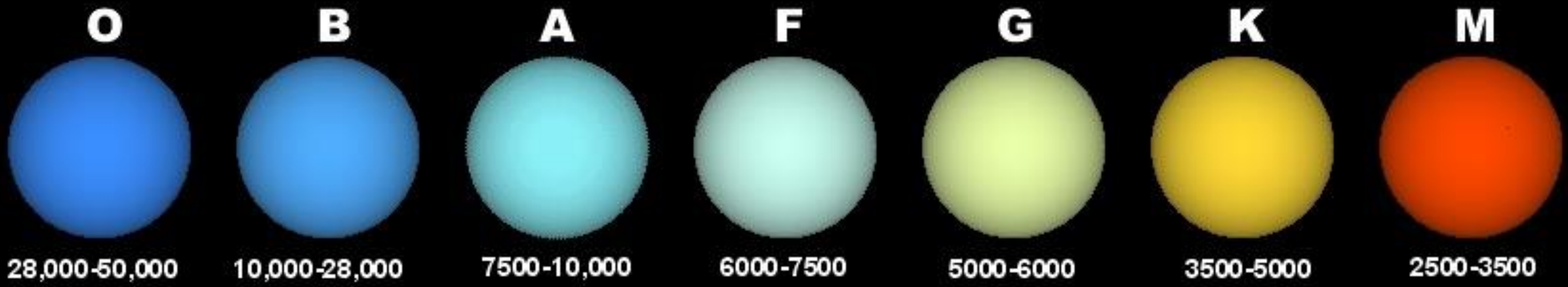
OBSERVABLE UNIVERSE

ii. **<u>Stars</u>** = large sphere of plasma hydrogen undergoing fusion, held together by gravity.

- <u>Classification</u>: stars are classified by two factors:

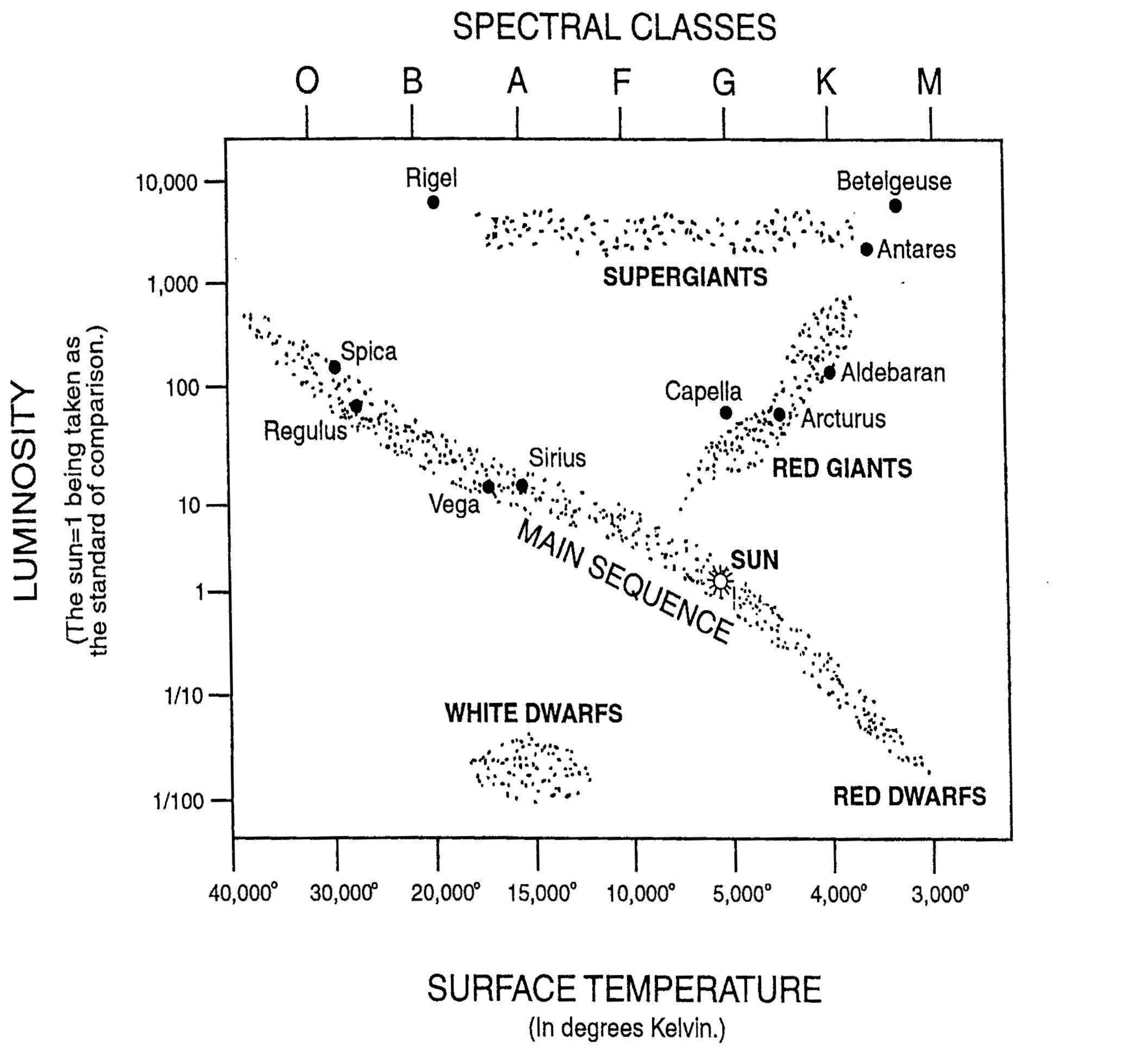
  - **Temperature**: estimated by a star's colour (blue = 50,000K to red = 2000K)

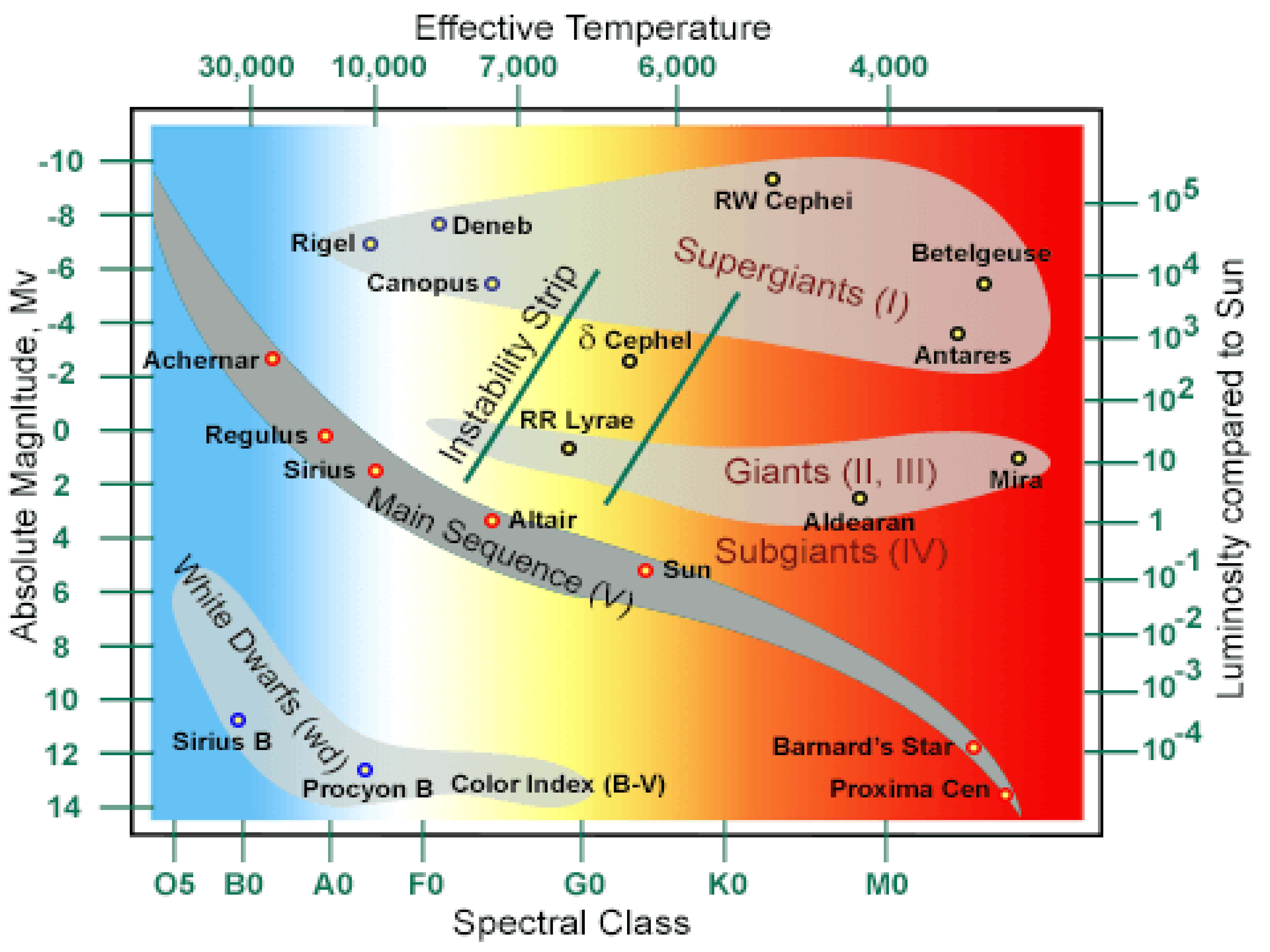
  - **Luminosity**: the brightness of a star (amount of energy output per second.)



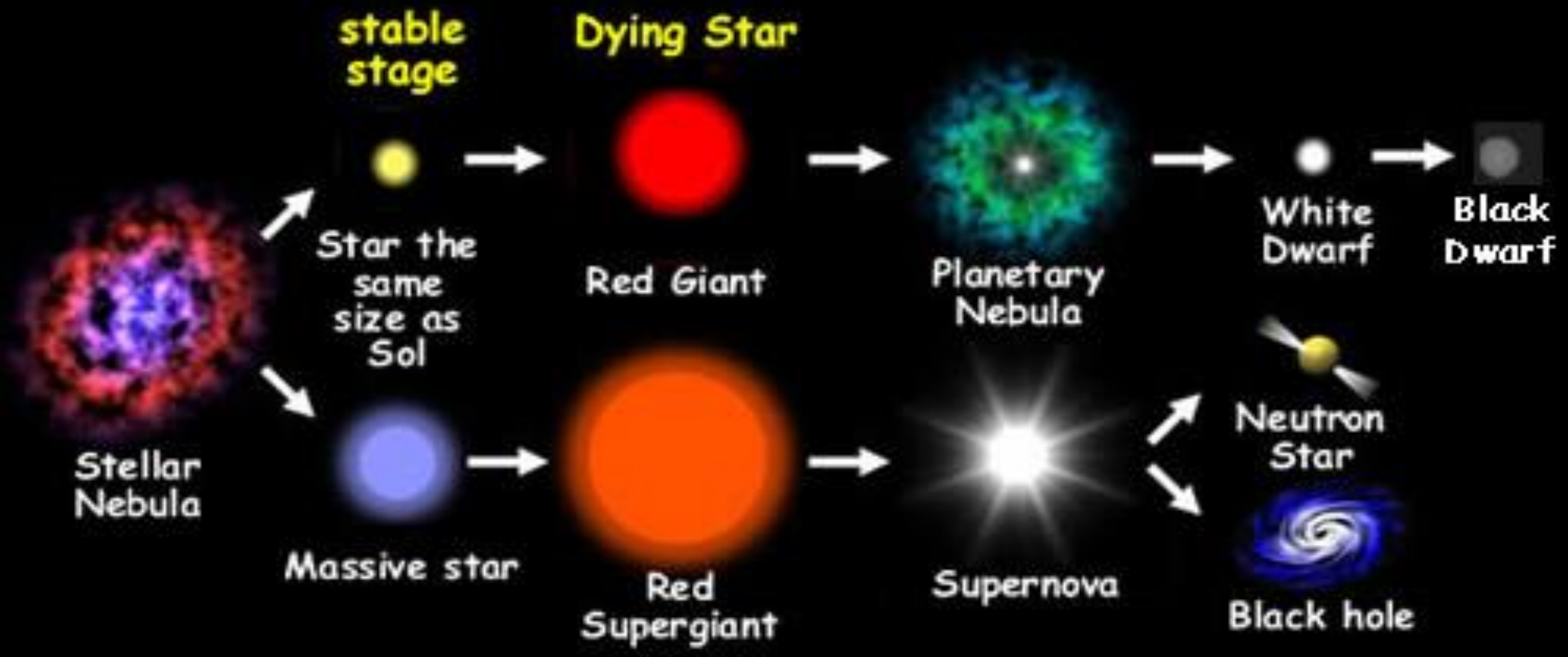
- Stars fall into several classes on a H-R diagram:

1. Main sequence
1. Giants
2. Supergiants
3. Dwarf stars

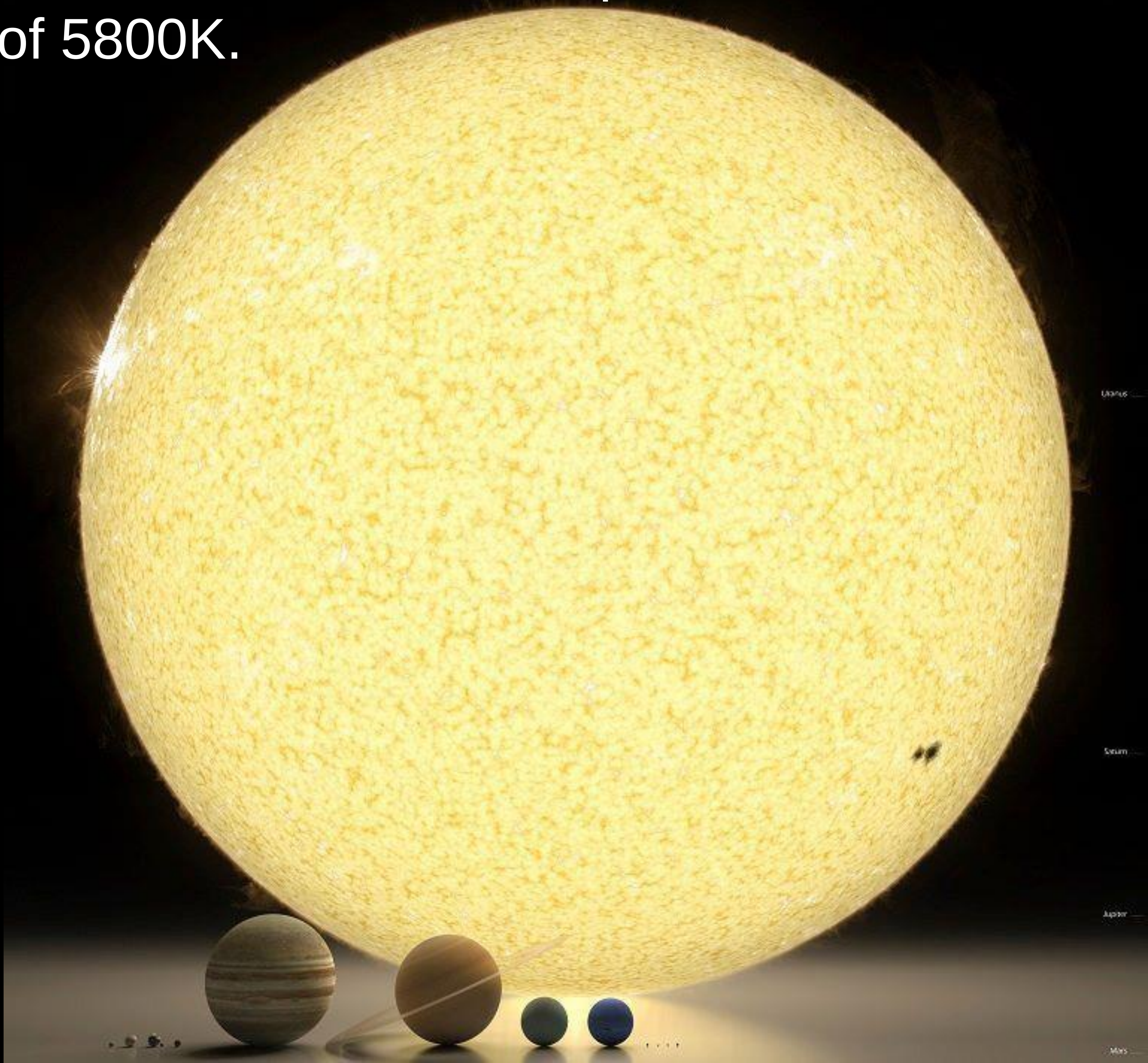



Effective Temperature
30,000
10,000
7,000
6,000
4,000
Absolute Magnitude, Mv
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
Luminosity compared to Sun
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
RW Cephei
Deneb
Rigel
Canopus
Betelgeuse
Supergiants (I)
Instability Strip
δ Cephei
Antares
Achernar
RR Lyrae
Regulus
Sirius
Giants (II, III)
Mira
Aldearan
Main Sequence (V)
Altair
Subgiants (IV)
Sun
White Dwarfs (wd)
Sirius B
Procyon B
Color Index (B-V)
Barnard's Star
Proxima Cen
O5
B0
A0
F0
G0
K0
M0
Spectral Class

- Stars pass though a predictable **life cycle**, from nebula to supernova…



-Our **Sun** is a medium-size star 100 million km in diameter, 109 Earths wide, a main sequence star with a temperature of 5800K.



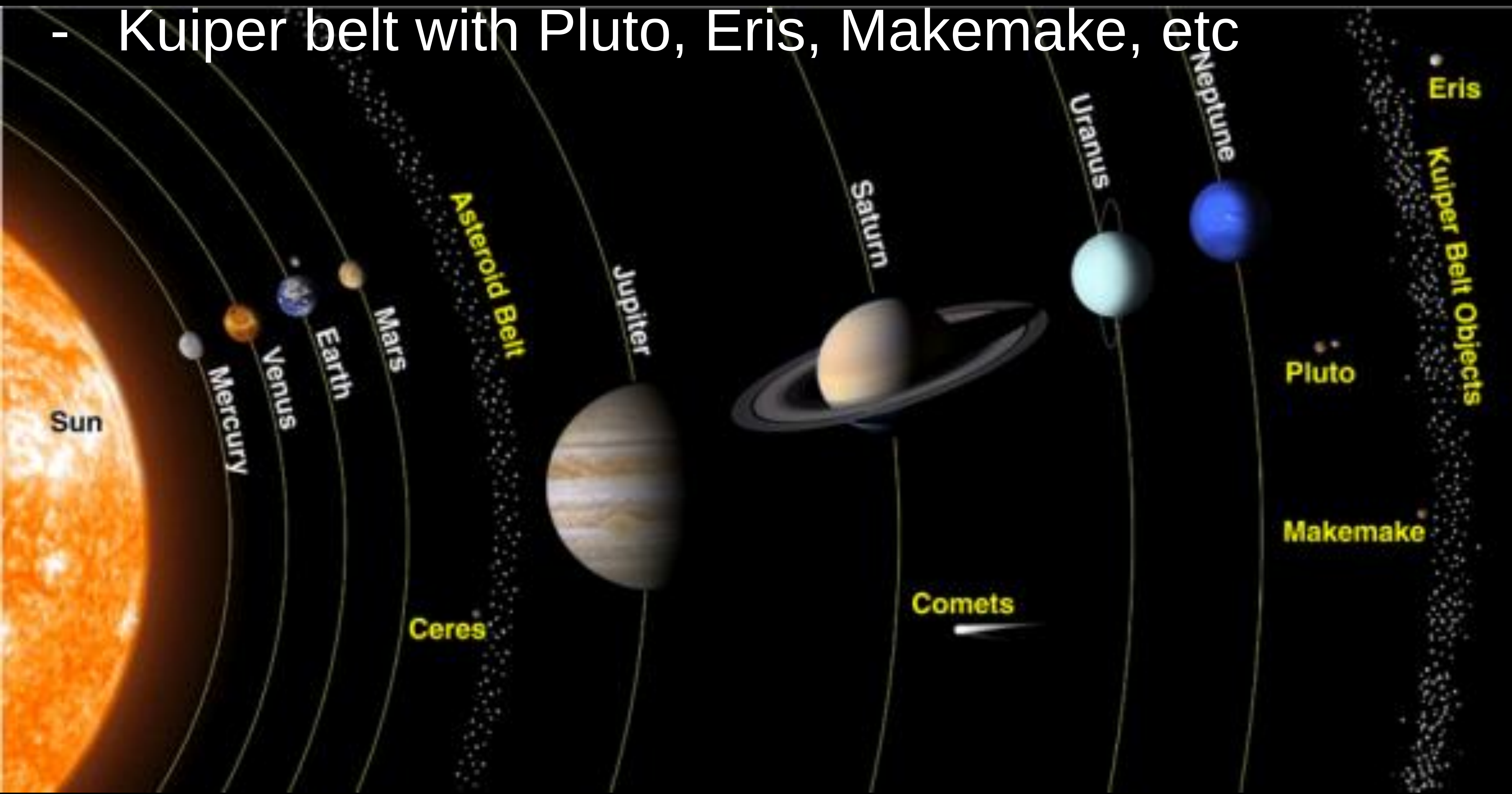

Solar Eclipse 2017
(Moon in front of the Sun)

iii. Planets and Moons

- Planets, dwarf planet, and rogue planets
- Exoplanets – planets orbiting other stars
- Moons – rocky, frozen ice, volcanic…
- Comets, asteroids, and meteoroids

Our solar system

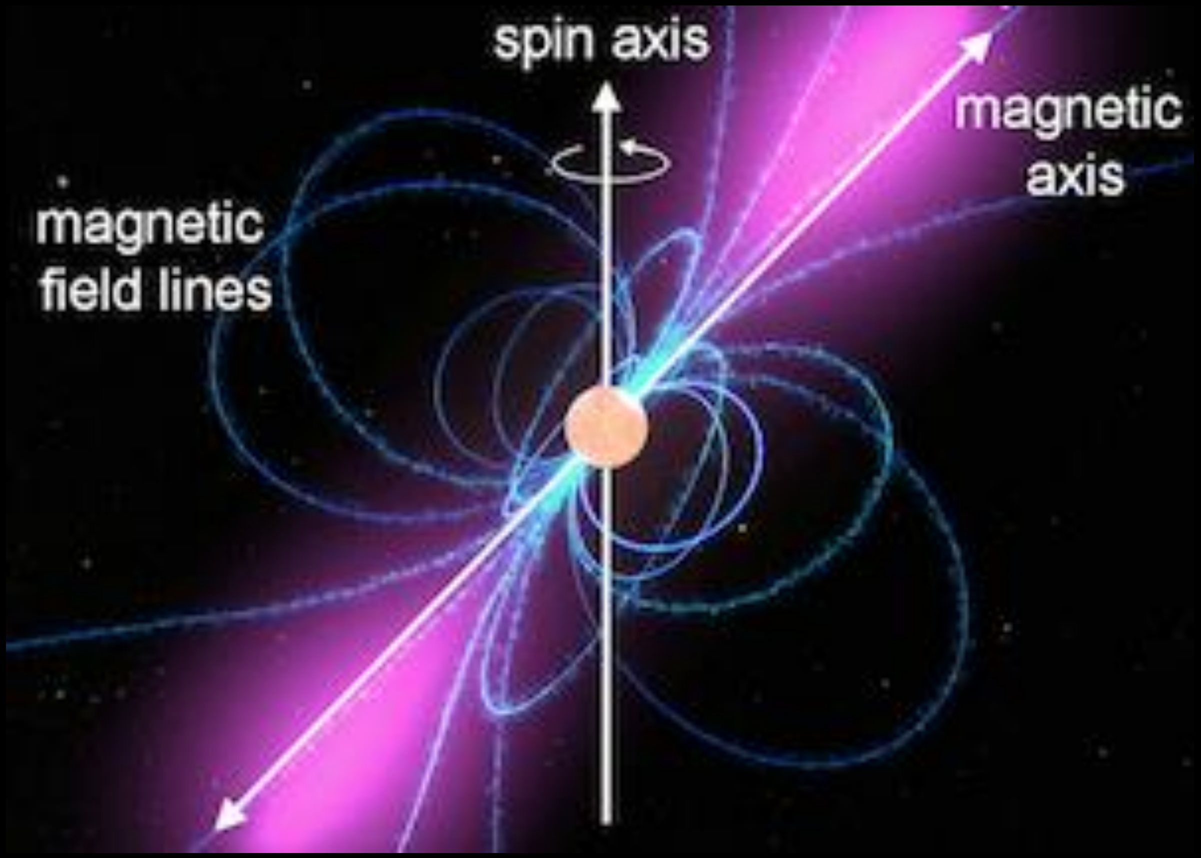
- *Terrestrial Objects:* Mercury, Venus, Earth, Mars
- Asteroid belt & Ceres
- Gas Giants: Jupiter, Saturn, Uranus, Neptune,
- Kuiper belt with Pluto, Eris, Makemake, etc



iv. Other objects in the universe

- Nebula = large cloud of interstellar gas (H_2) and dust, that contract to form stars.

- <u>Pulsars</u> = spinning neutron star that emits a beam of radiation, which pulse if it points towards Earth.



- <u>Cepheid variables</u> = supergiant stars that pulsate in brightness with a 1-100 day period, used to calculate astronomical distances.

- Black holes = infinitely-small, infinitely-dense object that even light cannot escape.

- <u>Quasars</u> = massive and remote object ejecting massive amounts of energy.

The Hubble Deep Field Photograph

The Hubble Space Telescope observed a tiny patch of empty space (imagine liking through a straw) for a week.

This is the image it took.

Each point of light is not a star. They are GALAXIES!
Imagine the trillions of planets orbiting the trillions of stars in each galaxy…

How did the universe form?

How will it end?

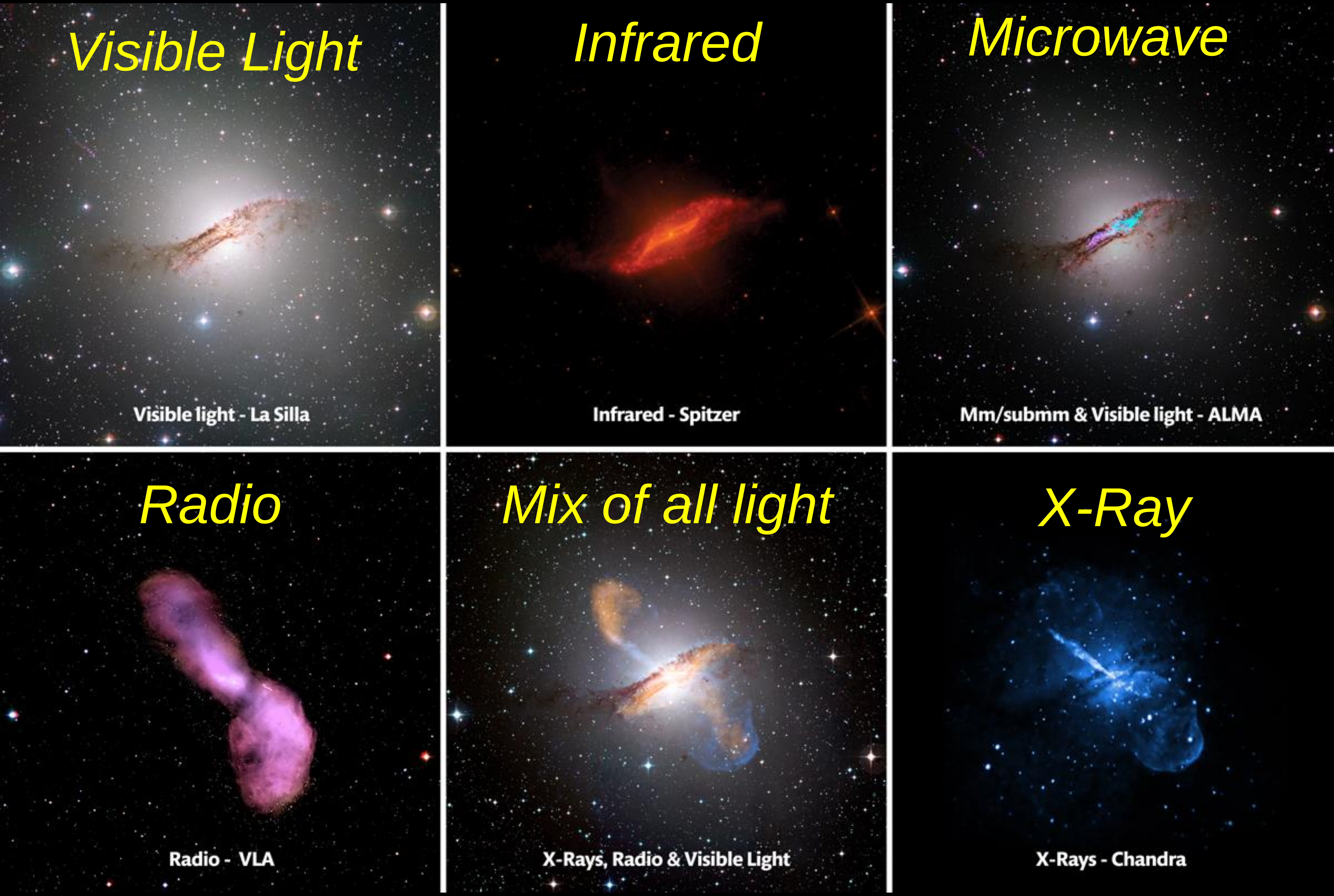
How do we know?

D. How do we know this?

Tools of Astronomy

i. **Radiation (light)** – bodies in space emit or reflect electromagnetic radiation as waves. Radiation, arranged on the electromagnetic spectrum, can allow scientists to study the universe.

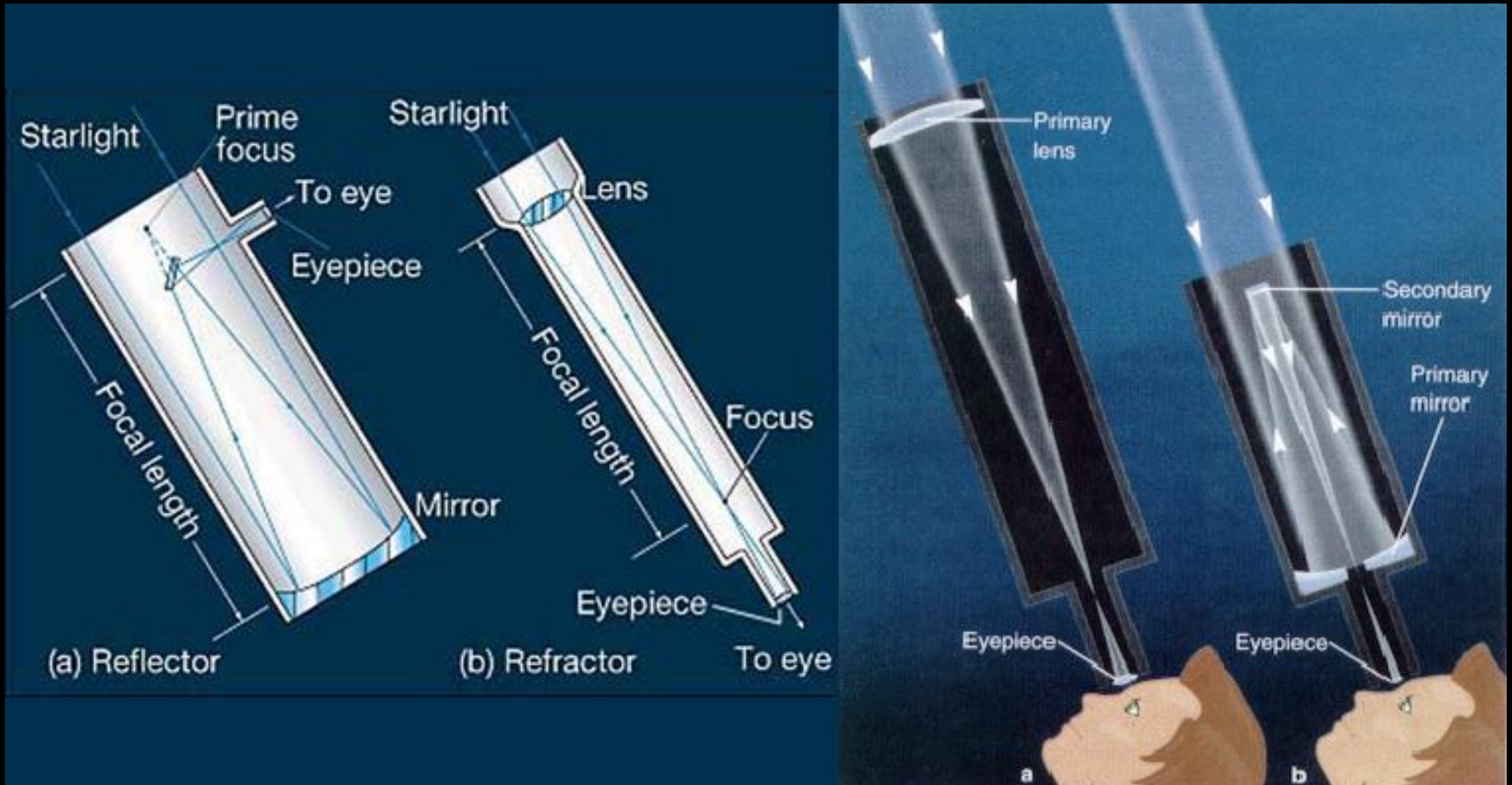
Radio
Microwave
Infrared
UV
X-Ray
Gamma Ray
Radio
60,000 nm
600 K
Infrared
1200-800 nm (10-3.6 um)
4,500 K
Optical
450-750 nm
6,000 K
Ultraviolet
400-200 nm
10,000 K
X-ray
100-10 nm
10,000,000 K
Multiwavelength Whirlpool Galaxy
COLD GAS: Radio waves reveal regions of gas cool enough for CO_2 molecules to exist.
COOL STARS: Infrared shows smaller cool red stars that make up most of the galaxy.
SOLAR STARS: Optical light comes from stars around the size of the Sun.
HOT STARS: Ultraviolet shows the larger hot blue stars that are less frequent in galaxies.
HOT GAS: X-rays are emitted from the hottest regions of gas where atoms are ionized.
COOL LOW ENERGY RADIATION
VISIBLE LIGHT
HOT HIGH ENERGY RADIATION


Visible Light
Visible light - La Silla
Infrared
Infrared - Spitzer
Microwave
Mm/submm & Visible light - ALMA
Radio
Radio - VLA
Mix of all light
X-Rays, Radio & Visible Light
X-Ray
X-Rays - Chandra

ii. <u>Ground-based Telescopes</u> - used to observe wavelengths beyond what humans can detect.

a) Refracting telescopes
– uses lenses to refract and focus visible light.

b) Reflecting telescopes
– uses mirrors to reflect and focus visible light.



c) Radio telescopes

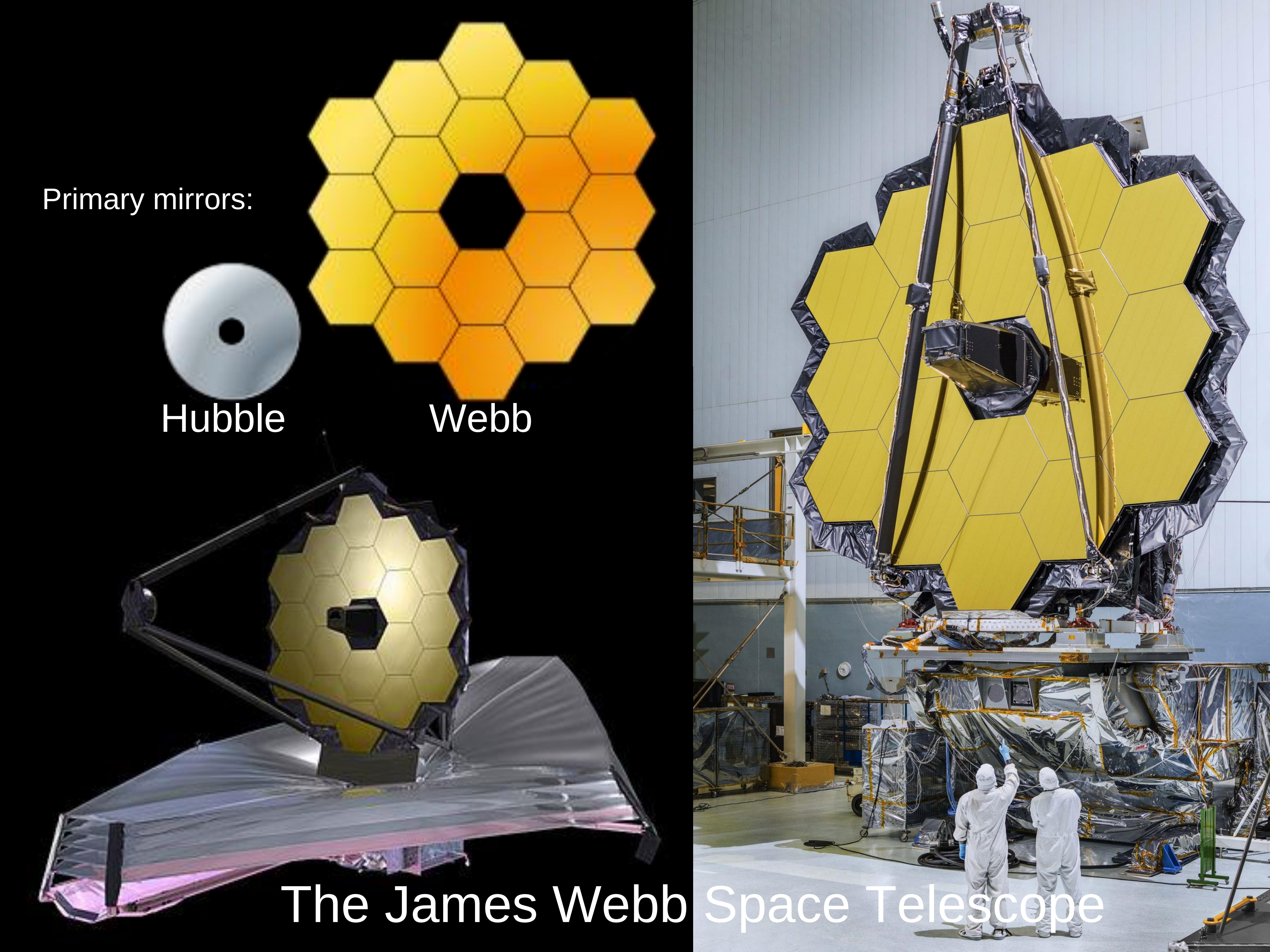
– collects the longer wavelengths, reflecting and focusing radio waves with a large dish.

iii. <u>Space Telescopes</u> – positioned above the atmosphere allows for much clearer collection of waves. Removes the “twinkle” of stars caused by fluctuations in the atmosphere.

Hubble Space Telescope
– launched in 1990, providing clear images in visible light, infrared and ultraviolet wavelengths.

James Webb Space Telescope
– to be launched in March 2021, the JWST will look further and clearer than Hubble in infrared wavelength.

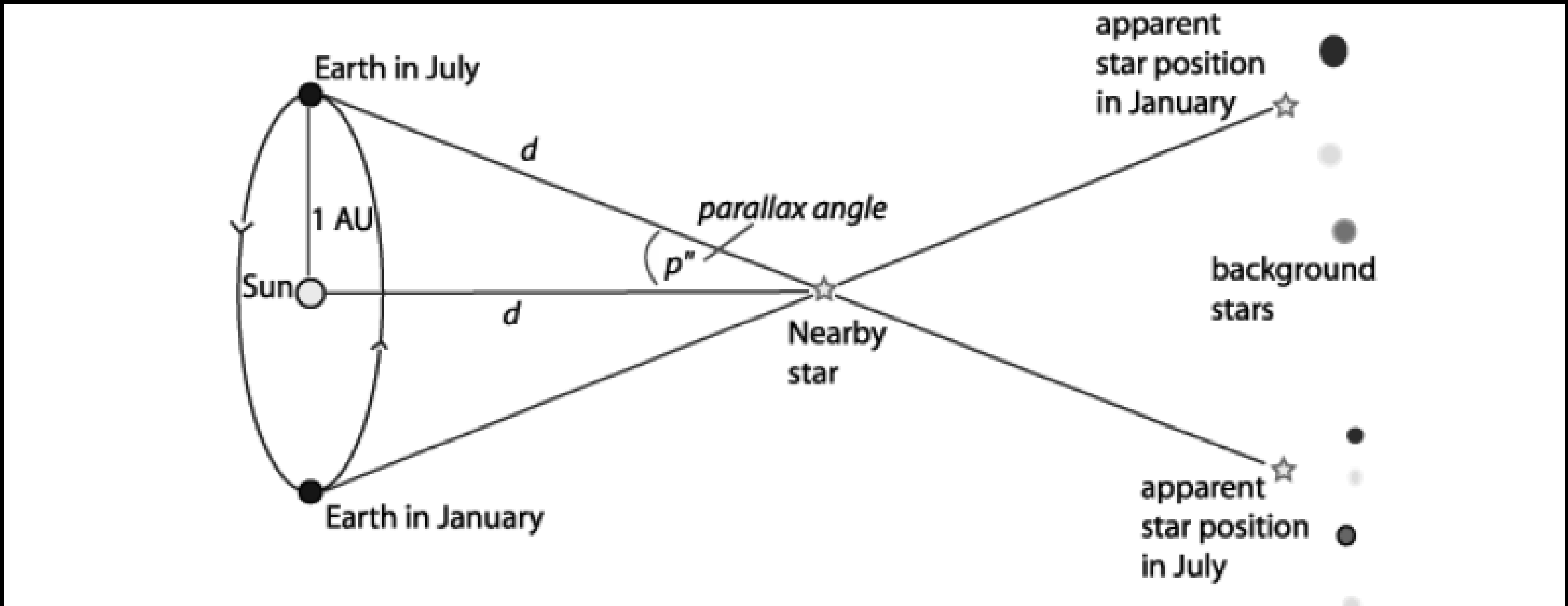
Others: **Kepler** (visible light), **Spitzer** (IR), **Chandra** (x-ray), **WMAP** (microwave)


Primary mirrors:
Hubble
Webb
The James Webb Space Telescope

Parallax

- To determine distances of stars from Earth, astronomers use parallax - the apparent shift in star position due to the observer orbiting around the sun.

- Using trigonometry, the distance can be calculated from the change in angle.



Parallax of nearby star

How did the universe form?

1. If we take the expanding universe and **rewind time**, it would have to have started from a single point (a **singularity**) – this is called the **Big Bang Theory.**

2. **The Big Bang Theory**

   The idea that the universe began as a point and has been expanding ever since.

   -The universe began as an infinitely hot, dense, and small gravitational singularity.

   -This initial singularity contained all the mass, energy, and spacetime of the universe.

   -Then, 13.8 billion years ago, inflation began rapidly

What did the universe inflate into?

Nothing, the universe is everything. There is no "outside"

MISCONCEPTION: the Big Bang was not an explosion. It was inflation/expansion.

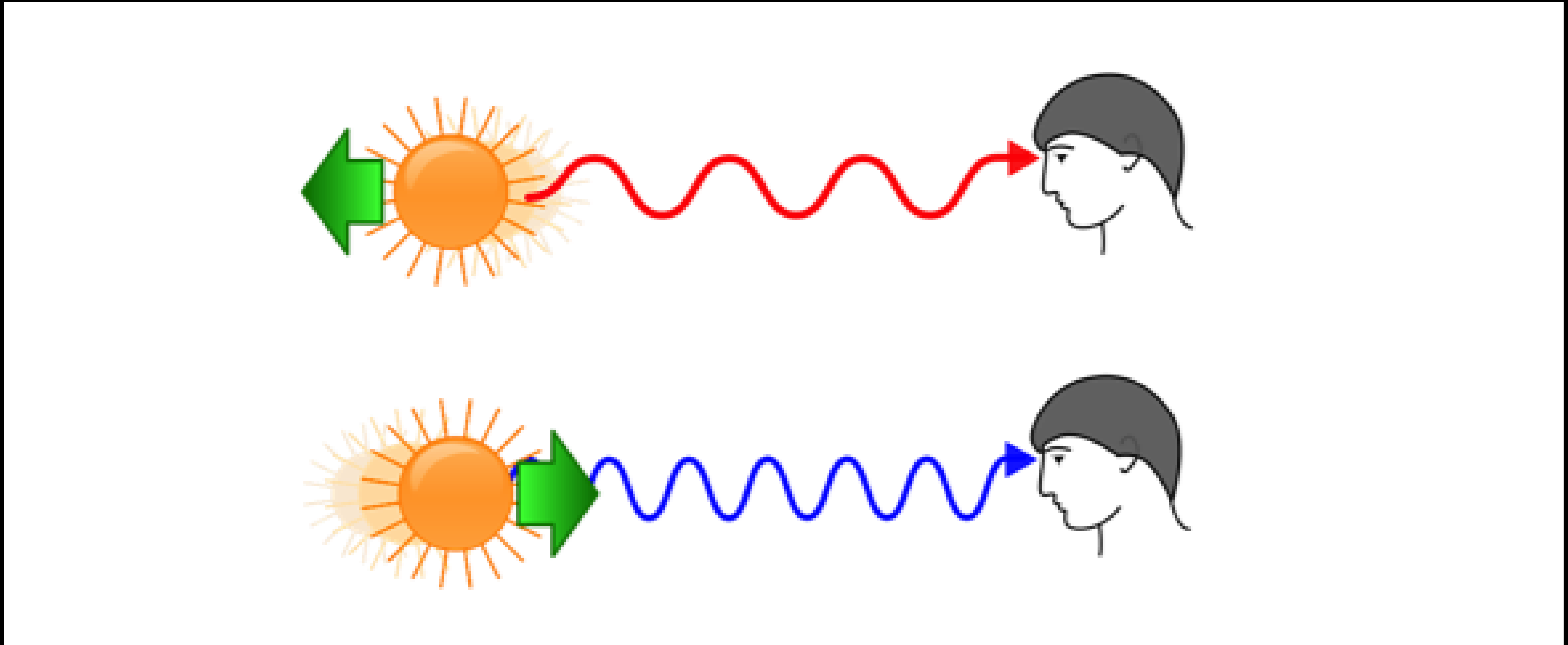
Evidence for the Big Bang theory:

1. Doppler Effect:

- Objects emit radiation/sound as waves.
- If the object moves away or towards the viewer, the waves elongate or compress – resulting in a shift in their spectra, either towards blue (shorter waves) or red (longer waves)

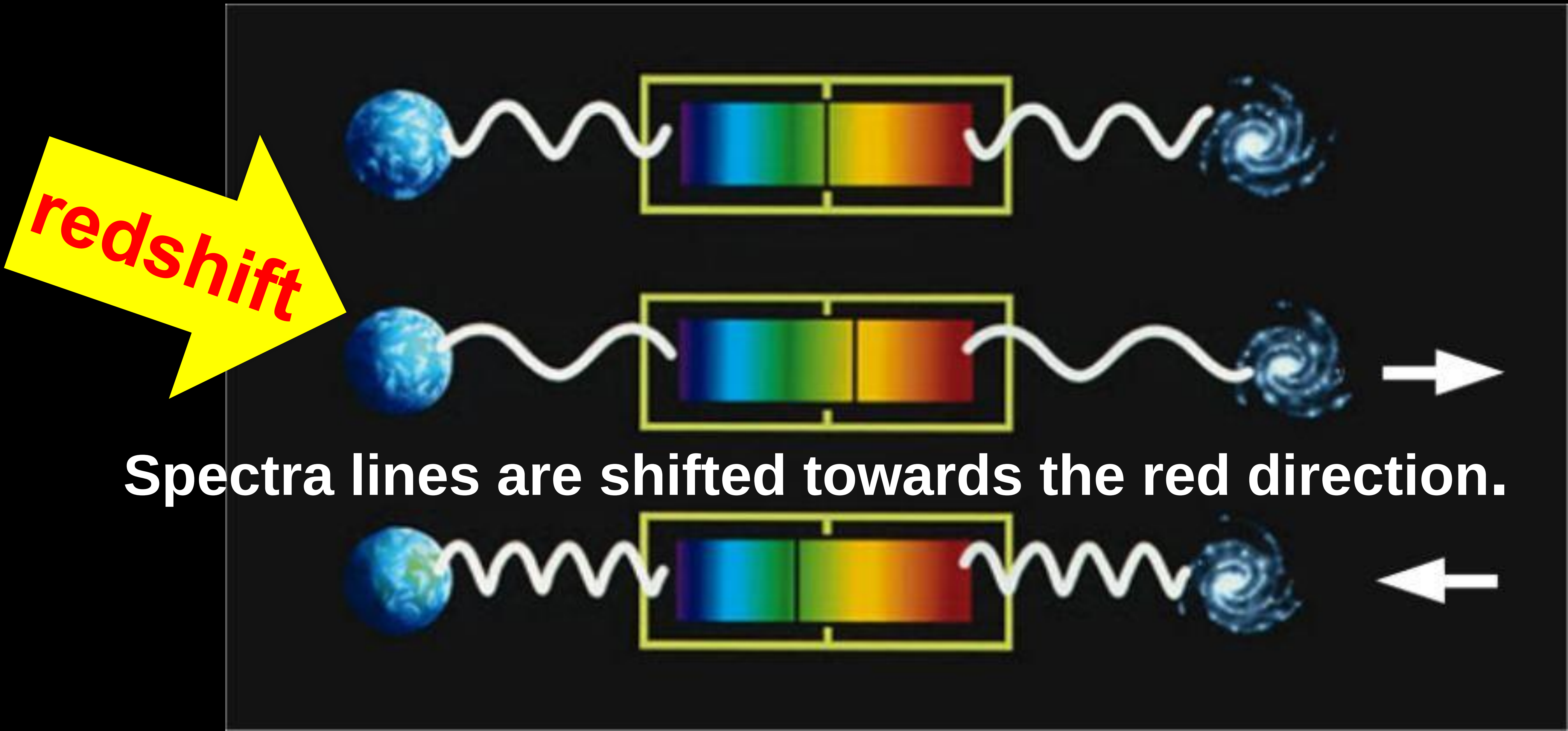
- **Blueshift** = if a star or galaxy is moving towards the observer, the light wavelengths are shortened, shifting to the blue end of the spectrum.

- **Redshift** = if a star or galaxy is moving away from the observer, the light wavelengths are lengthened, shifting to the red end of the spectrum.

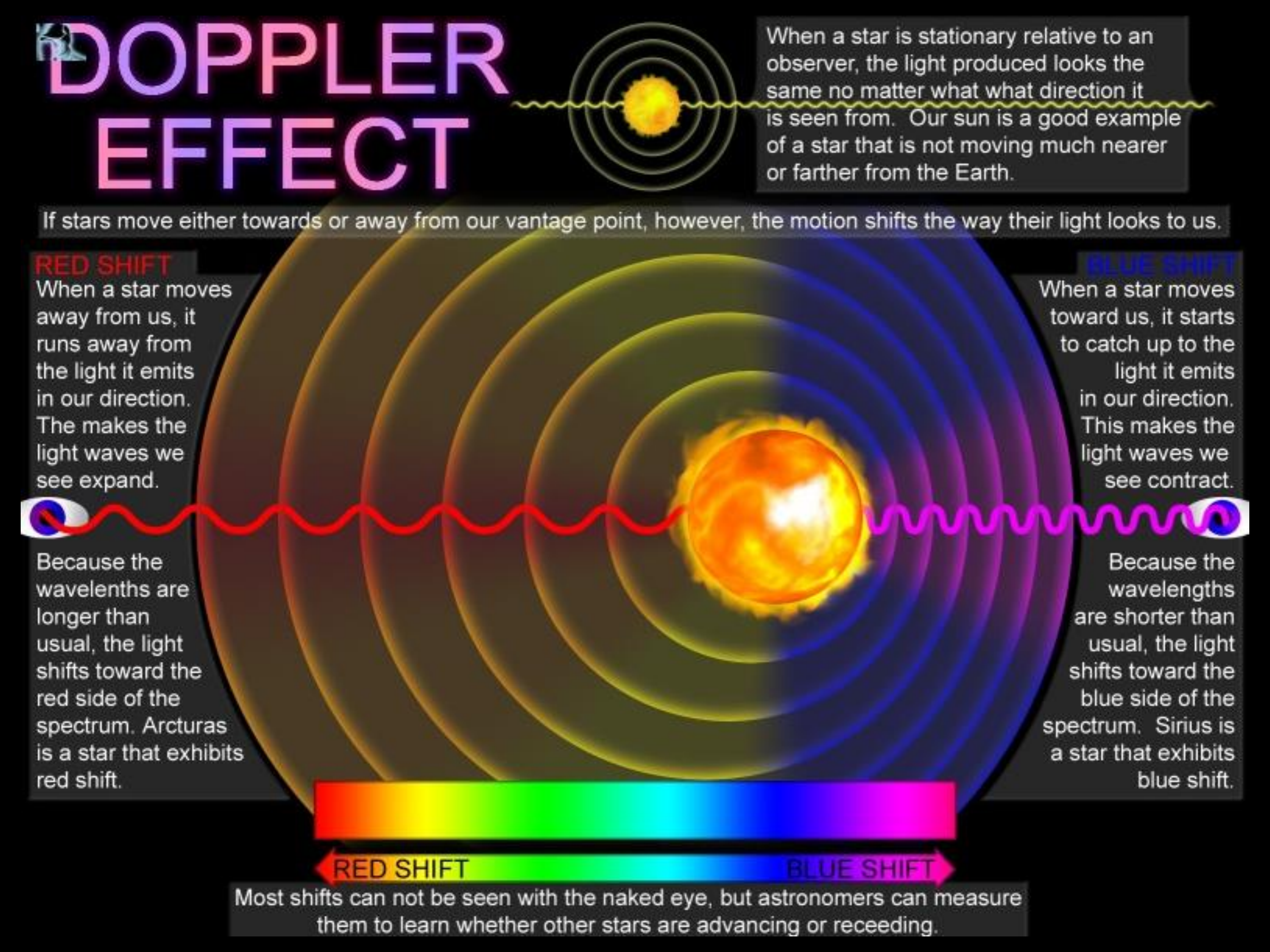


- In all directions around the Earth, when astronomers observe the distant stars and galaxies, they all show **redshift**.

- Redshift helps explains the expansion of the universe.



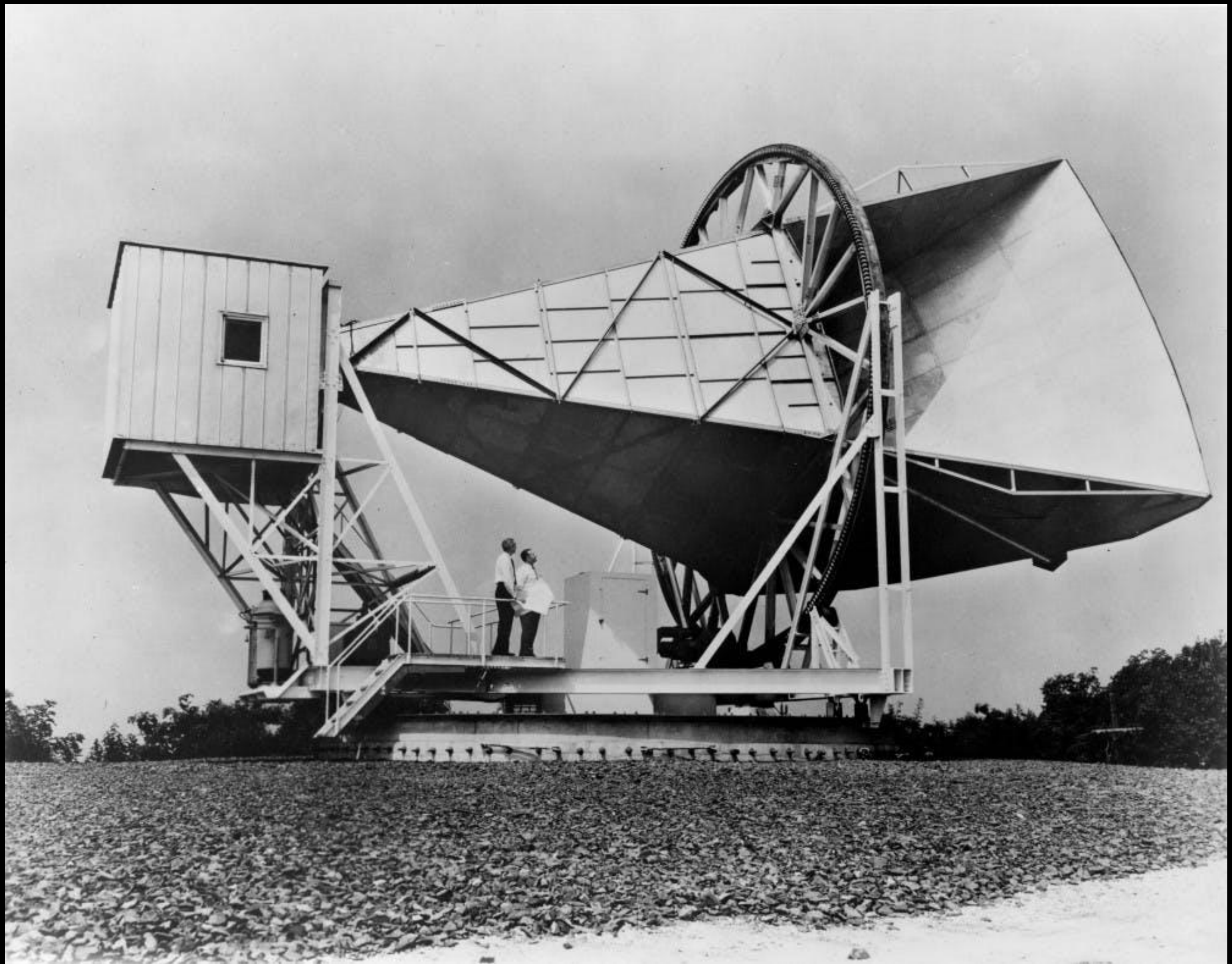
Spectra lines are shifted towards the red direction.


DOPPLER EFFECT
When a star is stationary relative to an observer, the light produced looks the same no matter what what direction it is seen from. Our sun is a good example of a star that is not moving much nearer or farther from the Earth.
If stars move either towards or away from our vantage point, however, the motion shifts the way their light looks to us.
RED SHIFT
When a star moves away from us, it runs away from the light it emits in our direction. The makes the light waves we see expand.
Because the wavelenths are longer than usual, the light shifts toward the red side of the spectrum. Arcturas is a star that exhibits red shift.
BLUE SHIFT
When a star moves toward us, it starts to catch up to the light it emits in our direction. This makes the light waves we see contract.
Because the wavelengths are shorter than usual, the light shifts toward the blue side of the spectrum. Sirius is a star that exhibits blue shift.
RED SHIFT
BLUE SHIFT
Most shifts can not be seen with the naked eye, but astronomers can measure them to learn whether other stars are advancing or receeding.

Cosmic Background Radiation

- In 1965, scientists discovered a persistent background noise in the radio antenna, called **cosmic background radiation**, coming from all directions. Weird…

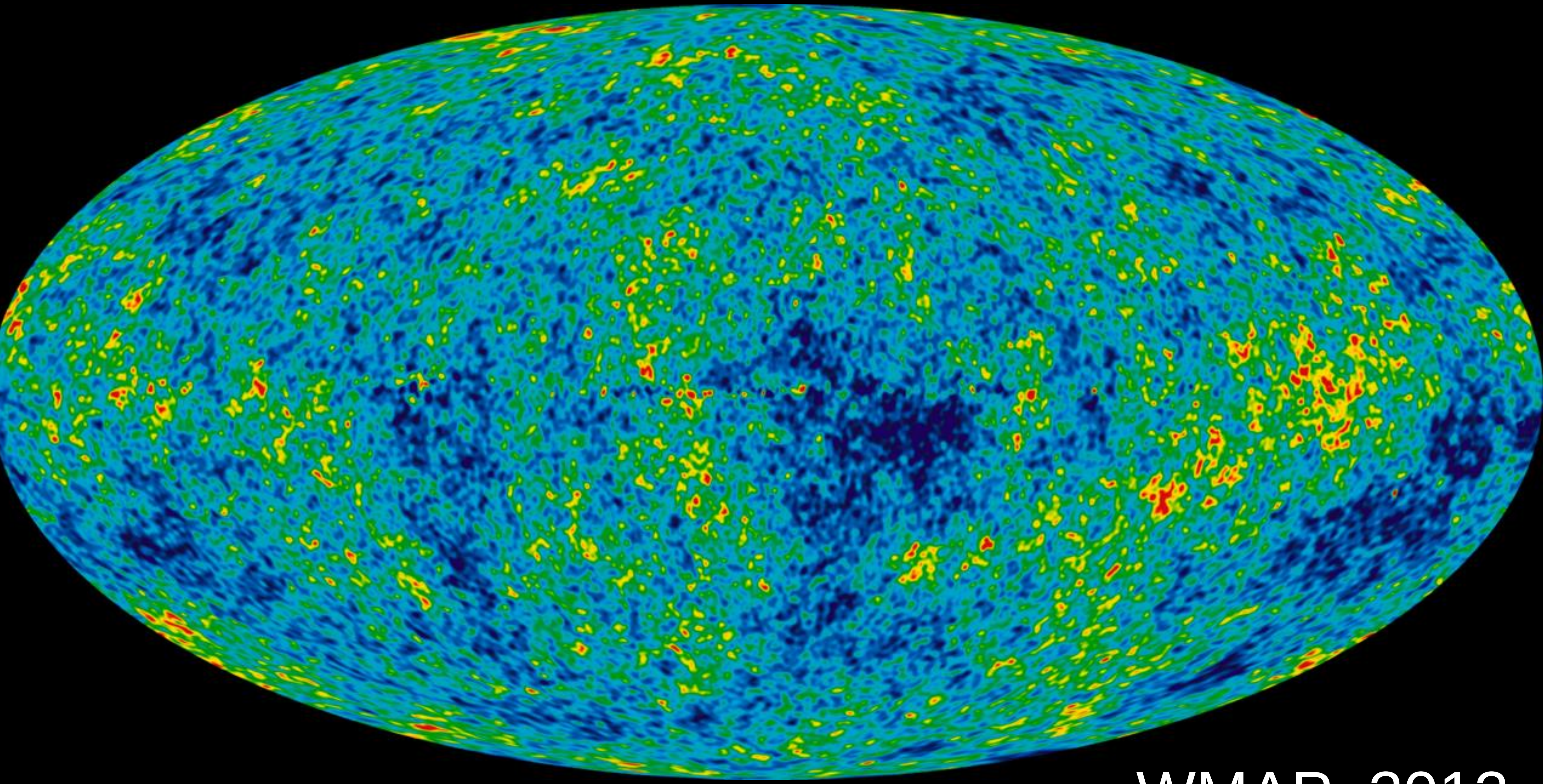
- Investigation discovered that this cosmic background radiation matched predicted properties of **leftover radiation** from the early hot phase **of the Big Bang.**



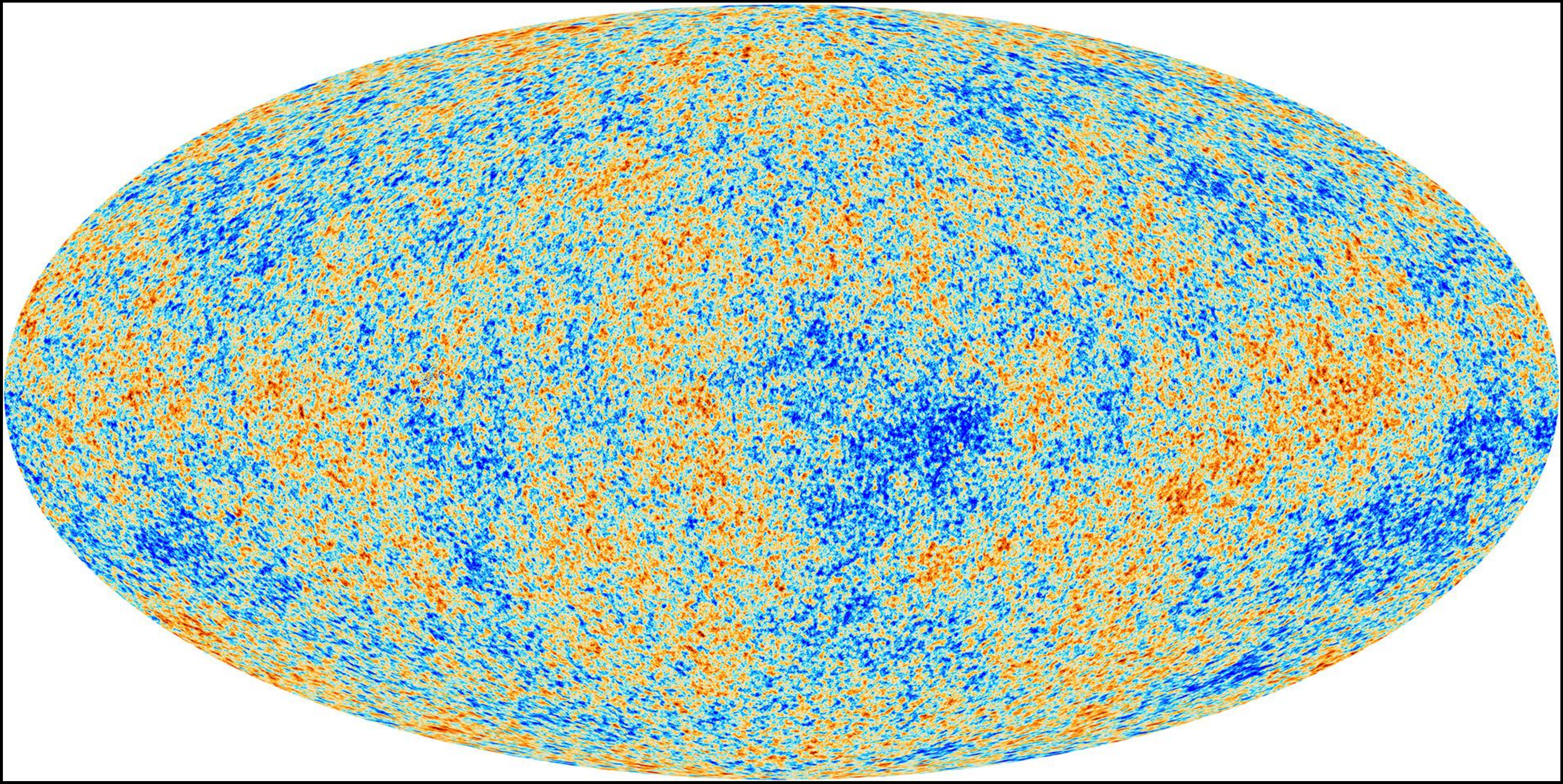
- In 2001, NASA launched the WMAP probe to map the radiation.

- The radiation has a wavelength of approximately 1 mm, making it **microwave radiation** in the radio portion of the EM spectrum.

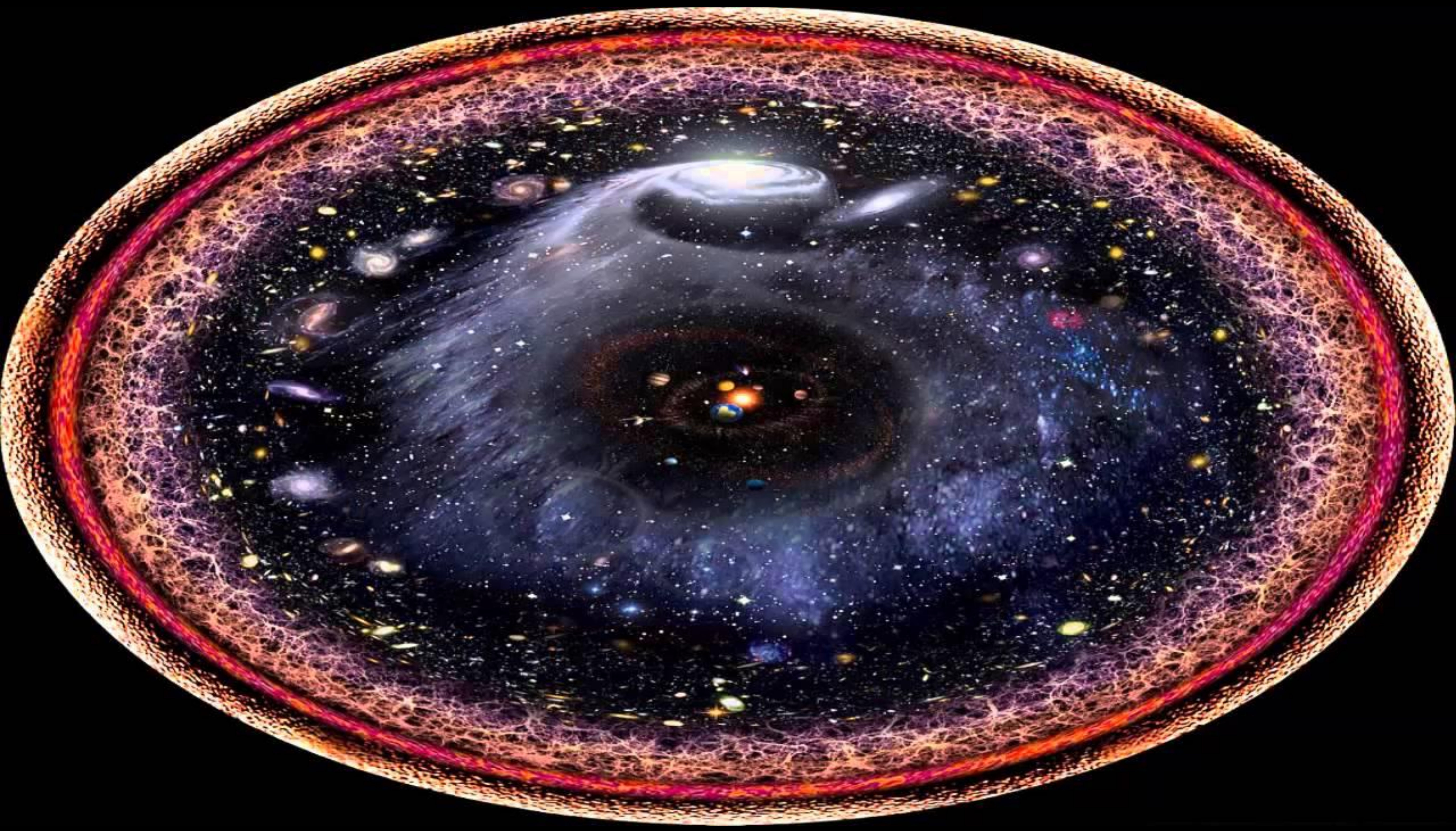
- Small temperature discrepancies of one-millionth of a degree in the cosmic background radiation may indicate the earliest major **structures** of the universe.



WMAP, 2012

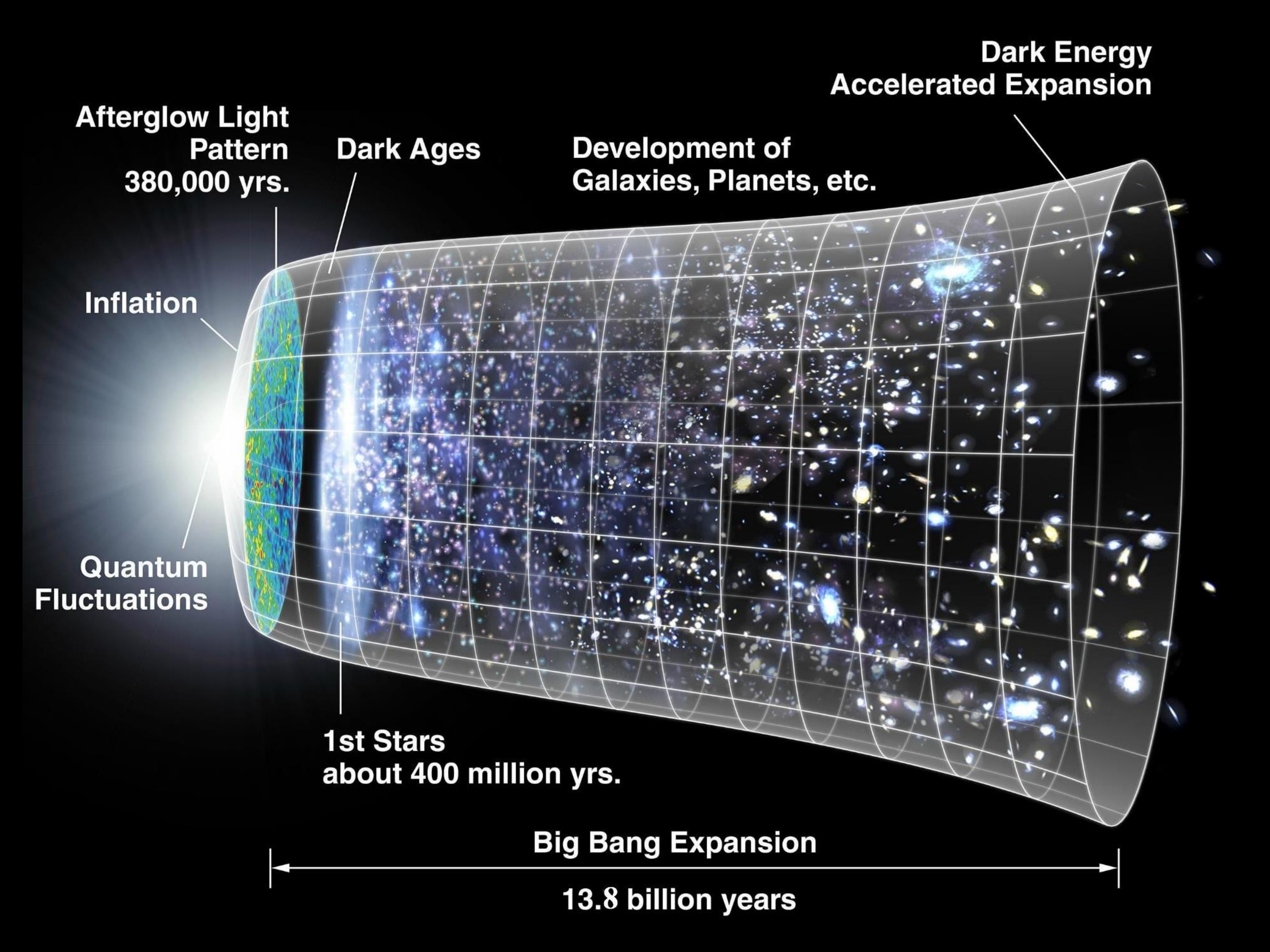


Planck, 2013



Artist imagining the universe, looking away from the Earth...
Present time in the middle, move back in time toward the edge.
CMB is the red circle.
Big Bang is the outside yellow circle.

The Evolution of the Universe through Time


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
380,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.8 billion years

How did the universe evolve?

1. **Age: 10^{-32} milliseconds –** size: infinitesimal to golf ball – 1,000,000,000,000,000,000,000,000,000°C
   - Inflation: In less than a nanosecond, a repulsive energy field inflates space and fills it with a soup of subatomic particles – quarks.

2. **Age: 0.01 milliseconds –** size**:** 0.1-trillionth present size – 10,000,000,000,000°C
   - Universe expands, cools. Quarks clump into protons and neutrons. Dark matter forms?

3. **Age: 0.01 to 200 seconds –** size**:** 1-billionth present size – 100,000,000°C
   - Universe continues to cool, hydrogen & helium nuclei forms. Too hot for atoms. No light.

4. **Age: 380,000 years old** – size: 0.09% present size – 10,000°C
   - First atoms: electrons begin orbiting nuclei. Cosmic background radiation begins.
   - Dark ages.

5. **Age: 300 million years old** – size 10% present size – -200°C

- First stars: Dense clouds collapse due to gravity, and nuclear fusion occurs. The first stars emit the first visible light. Galaxies, solar systems, and planets form.

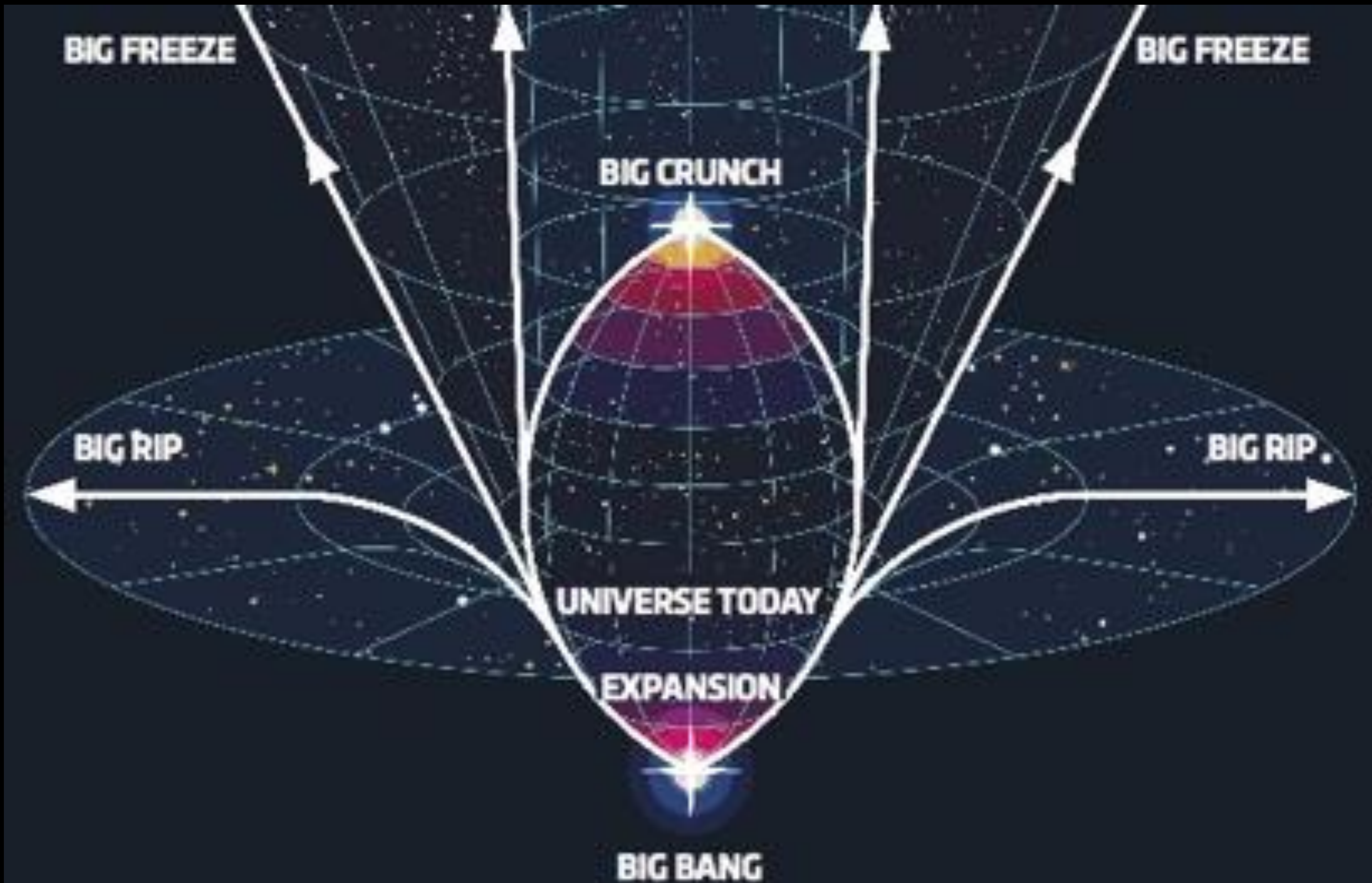
6. **Age: 10 billion years old** – size: 77% present size – -270°C

- Universe expansion begins to accelerate again – due to dark energy. First stars die, sending heavier elements into the universe.

7. **Age: 13.8 billion years old –** size: 100% present size – -270°C

- Today: the universe continues to expand, becoming less dense. Fewer stars form now. You are born.

What is the future of the Universe?



How will the universe end?

- How the universe will end depends on which force ends up being greater:

gravity or *dark energy*

Possible futures…

- **Big Rip**
- **Big Crunch**
- **Big Freeze**

Big Rip

gravity < dark energy expansion

- Expansion accelerates even more, eventually becoming infinite. Atoms would separate, until galaxies, stars, and planets tear apart, leaving a universe of disconnected particles.

Big Crunch

gravity > dark energy expansion

- Expansion slows down, and gravity pulls all matter together. The universe would shrink, causing stars, planets, and galaxies to crash into each other, until the universe collapses into another gravitational **singularity**.

- **Big Bounce** is a theoretical model where the singularity creates a new universe, and this Big Bang and Big Crunch have repeated at infinitum.

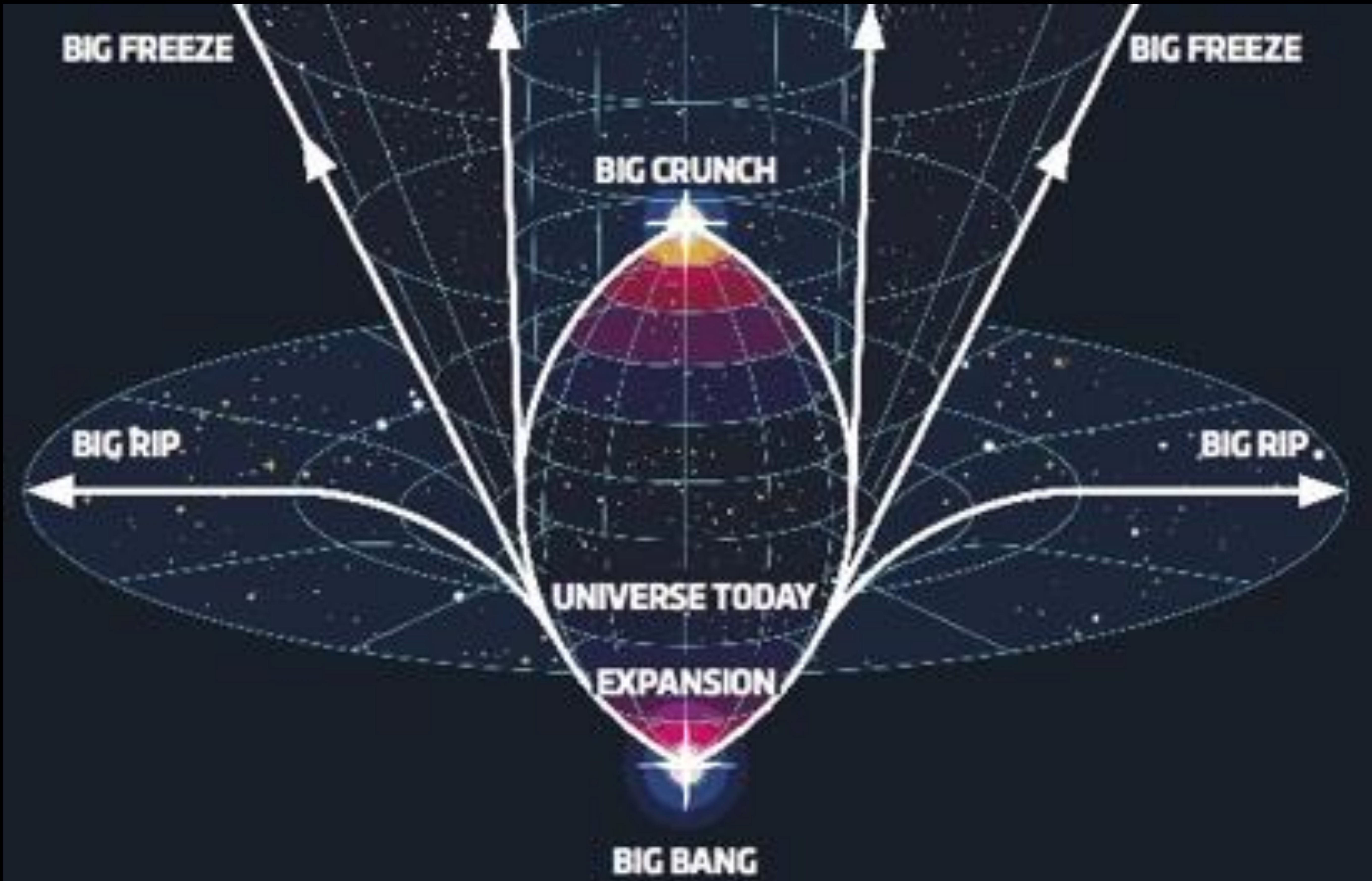
Big Freeze

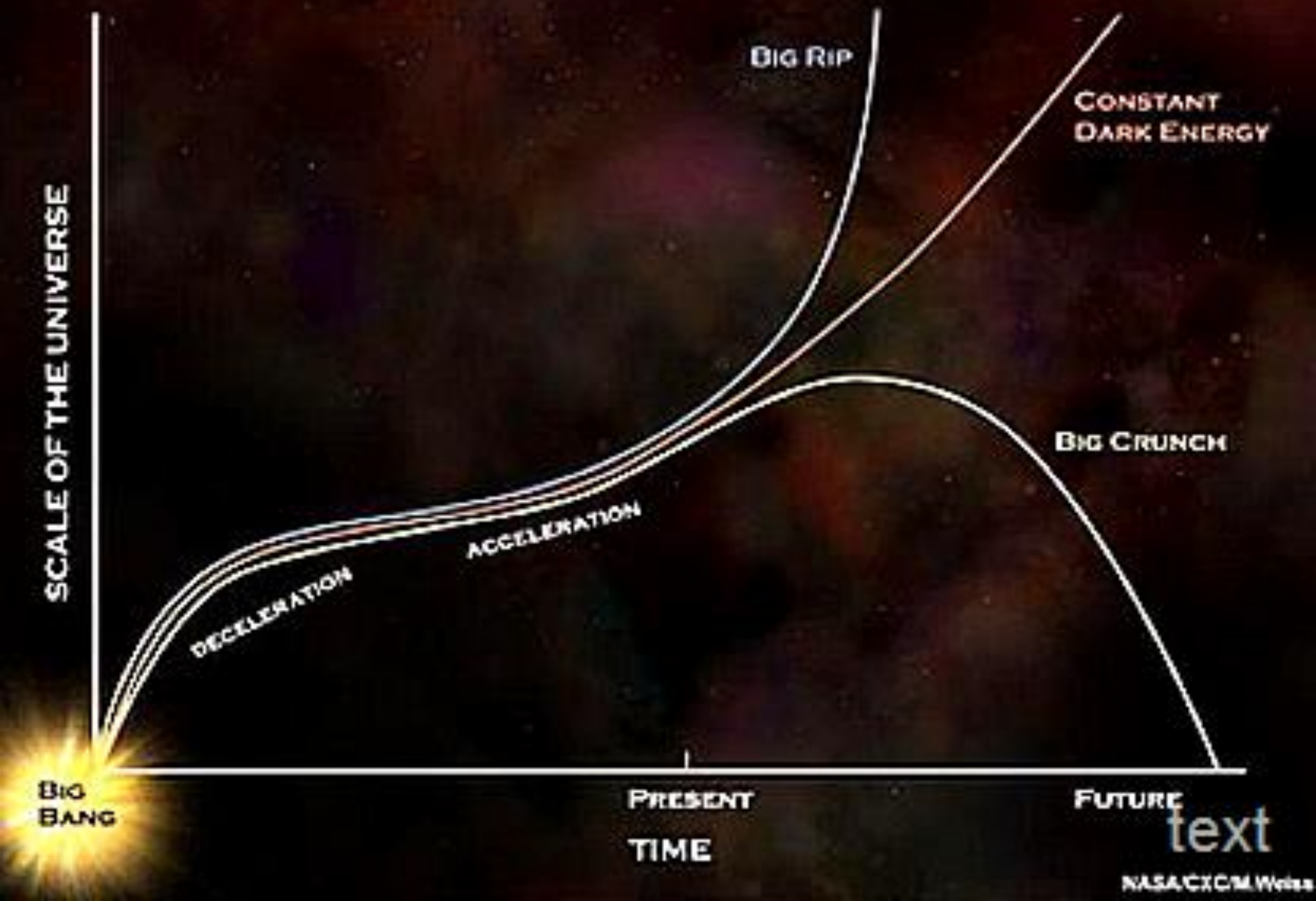
gravity = dark energy expansion

- Expansion leads to maximum ENTROPY, a state of maximum disorder.

- **Heat Death**: eventually, all stars will die; with gas will be distributed so evenly that no new stars are born. All that will be left will be black holes, until they fade away (through Hawking radiation), leaving **no energy (heat)** and nothing to record time.
- Time would cease to exist.

- This is the most **likely** end according to cosmology.


BIG FREEZE
BIG FREEZE
BIG CRUNCH
BIG RIP
BIG RIP
UNIVERSE TODAY
EXPANSION
BIG BANG


SCALE OF THE UNIVERSE
BIG RIP
CONSTANT DARK ENERGY
BIG CRUNCH
DECELERATION
ACCELERATION
BIG BANG
PRESENT
FUTURE
TIME
text
NASA/CXC/M.Weiss

What is your place in the Universe?